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# THESIS

A FORCE STRUCTURE DESIGN MODEL

by

Charles V. Fletcher

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Thesis Advisor: Samuel H. Parry

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# A Force Structure Design Model

by

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## ABSTRACT

This thesis describes a systematic force structure design methodology that uses force effectiveness, risk, and cost to design and compare force structures. The requirements for military force are determined by predicting the future military situation in terms of conflict probabilities. These requirements for military force are used to design a balanced force structure. The balance of the force structure is measured by force effectiveness attributes. The thesis uses relaxed mixed integer programming to optimally fill the force requirements by providing a balanced force structure with currently available forces.

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## LIST OF ABBREVIATIONS

AA  Air-to-Air Wings

AC  Aircraft Carrier Battle Groups

AG  Air-to-Ground Wings

AHP  Analytical Hierarchy Process

CALOW  Contingency and Limited Objective War

CINC  Commanders in Chief

DEPL  Deployability

DoD  Department of Defense

DPG  Defense Planning Guidance

DPRB  Defense Planning and Resource Board

FAR(I)  Force Attribute Request

GAMS  General Algebraic Modeling System

HD  Heavy Divisions

HIGHINT  High Intensity Warfare

Ideal Force Matrix  Matrix F

INSURG  Guerrilla Warfare/ Insurgency

JCS-J8  Joint Chiefs of Staff, Force Structure and Design

JSCP  Joint Services Contingency Plan

JSR  Joint Strategy Review

LATAM  Latin America

LD  Light Divisions

LETH  Lethality

MAPS  Military Applications Program Software

MATRIX C  Probability of conflict matrix

MD  Marine Divisions

MIDINT  Mid Intensity Warfare

MOBL  Mobility

NCA  The National Command Authority

NMS  National Military Strategy

POLI  Political Impact

POM  Program Objective Memorandums

SEASIA  Southeast Asia

SF  Special Forces Groups

SG  Surface Action Groups

SURV  Survivability

SUST  Sustainability

SWASIA  Southwest Asia

TERROR  Terrorism

V(J)  Consequence Vector

W(J)  Weighted Consequence Vector

ZOOM  Zero/One Optimization Method

# I. INTRODUCTION

> There is a need -- not new but now more urgent -- for a relatively simple, clear framework to help gauge whether our Defense force level and mix are roughly right, in a fashion that does no great violence to any of the essential elements involved. (Hughes, 1978, p.1)

The design of modern force structure is a complicated process involving many competing elements. Currently, force structure design is driven by political pressure, budget constraints, and service rivalry. This process unquestionably impacts on the United States ability to prctect its national interests in peacetime and in war. It is important to insure the force structure decision-making process considers alternative proposals and analyzes these proposals in a fair, efficient manner. In order to evaluate different force structure proposals, a system must be used to consider the trade-offs between the competing elements of force structure. The system that drives force structure design should be consistent, recoverable and transparent.

There are several approaches to developing force structure. Each approach uses a determination of risk to set the limit on the total force size or cost. In this context 'risk' is the subjective assessment of the decision makers that the policy adopted will benefit the United States. One method of force structure design considers only effectiveness and accepts little or no risk. A low risk force structure must provide for an effective response to any military challenge that threatens the nation or its interests. In this case the nation must be prepared for every contingency, and to do so the military force will be huge and expensive. An effective force is expensive to maintain in peacetime, but is less expensive (in dollars and lives) when it has to fight a war.

A second approach will accept risk in exchange for a less expensive military force. The military provides a less expensive force by cutting material acquisition, research and development, training or personnel, which in turn reduces the effectiveness of the force. A less effective force in peacetime will cost more in a war than an effective force (in dollars and lives). An example of this tradeoff is the difference between the United States forces entering the Korean War and the forces entering the Persian Gulf War.

To optimize force structure, a balance between cost and force effectiveness must be reached. The risk that is assumed must be built into the force design system so that military leaders and politicians know what they are planning for and getting for their budget dollar. Budget dollars should not be spent on tanks, airplanes and ships; instead, the dollars should be spent on force effectiveness and the force effectiveness used to reduce risk to the nation. This force design system trades money for force effectiveness, and force effectiveness for risk. An excerpt from a recent United States Army posture statement reflects the intent of the Army to follow the use of cost (affordability), risk and effectiveness (capabilities) in building force structure.

> Choices about the size and composition of the Total Army are based upon assessments of current and potential threats to the Nation and of the capability required to meet them. These assessments are tempered by considerations of affordability and risk. (Stone, 1991, p 47)

This thesis presents a systematic force design procedure that incorporates the subjective elements of risk and effectiveness with the objective determination of cost in finding an optimal solution to the force design problem. Assumptions of risk and effectiveness made during the procedure will be recoverable and transparent. The total force design process will be consistent with constant inputs. With this process and its characteristics, a force design system can be designed that builds forces based on risk, cost, and effectiveness.

This thesis will describe a procedure that uses inputs of force effectiveness (an attribute(I) by level of conflict(J) matrix), conflict predictions (a location(K) by level of conflict(J) matrix), and conflict consequences (a vector of level of conflict(J)) to develop a force attribute request. By subjectively weighting the conflict predictions with the consequences of conflict, the program will develop an ideal force mix. The Force Attribute Request, (FAR(I)), is a normalized vector of real numbers. The FAR will describe a force that has the best percentage of each attribute to engage in the type (level and location) of conflicts that are predicted by the user.

The user will input constraints to the system, such as total force size and minimum and maximum amounts for each unit type. The procedure will use relaxed mixed integer programming to optimally allocate the units to fill force requirements. The objective of the program will be to fill the force requirements with forces and to have a final force that has an attribute mix that is as close as possible to the TAR vector.

# II. BACKGROUND

## A. CURRENT FORCE STRUCTURE DESIGN

The current force structure design process is a four year cycle. The cycle contains five phases: a twenty-two month long planning phase, an eight month long programming phase, a four month long budgeting phase, an eight month long enactment phase and a four month long execution phase (JCS-J8 Force Overview Briefing, 3 Mar 1990). The National Command Authority (NCA), the Commanders in Chief (CINC), and the service chiefs provide guidance to a Joint Strategy Review (JSR). The JSR considers threat assessments, CINCs priorities and world conditions. The JSR is a one year long process in which each service and CINC has continuing input. At the end of the JSR, the Chairman's guidance is produced. The Chairman's guidance is the single document that describes what the combined military forces believe is a suitable force structure.

The issuance of the President's Fiscal Guidance occurs after the Chairman has developed his guidance. The President's Fiscal Guidance causes a policy review to occur within the Office of the Secretary of Defense and the flow of guidance continues on to impact on the Chairman's Guidance. Throughout the planning phase, yearly reviews are held of the current contingency planning guidance, changes and updates are added as necessary. Also yearly, a joint Military Net Assessment is held that compares United States Military power with that of the Soviet Union. Advances in technology, changing strategies and world politics are reviewed in the context of military power and what the effects of the United States' position is on the current global balance of military power.

The planning phase ends with the production of two documents: the National Military Strategy (NMS) and the Defence Planning Guidance (DPG). The NMS is the document that details each mission the United States is likely to face and lists military force requirements that are available to handle each threat. The NMS is a mission oriented force design document. The DPG details how the fiscal budget is to be spent on defense. The DPG is a budget oriented force design document that details how the projected force structure will be supported financially.

The programming phase centers around the development of the Program Objective Memorandums (POM) by each service. The POMs are the service's proposed funding documents. The POMs are developed to support both the DPG and the NMS. IVn addition, the NMS is refined into a more detailed prediction of contingency operations and requirements called the Joint Services Contingency Plan (JSCP). The POMs are reviewed by the Chairman of the Joint Chiefs of Staff, who publishes a Chairman's Program assessment. All unresolved or conflicting issues are studied individually by an integrated panel from the CINCs, the JCS, and the OSD. The final aspect of the programming phase is the meeting of the Defense Planning and Resource Board (DPRB). The DPRB formally locks in political support behind the proposed force structure. For the most part, the design of force structure ends after the DPRB. The budgeting, enactment and execution phases are basically a follow-up of the outcome of the DPRB.

## B. THESIS MOTIVATION

The process of force structure design has proven very tedious and prone to excessive political infighting. As the budget for military expenditures becomes tighter, the level of competition between services will increase. As the world situation continues to rapidly change with the disintegration of the Warsaw Pact, more uncertainty will arise in determining what the military force of the United States must be able to accomplish in association with allies for the specific situation. The United States military objectives are becoming less easily identified, but the budget is clearly going to decrease. Changes are coming in force structure; "forces will be restructured so as to support the new strategy most effectively and efficiently"(DoD News Release, 4 Feb, p.3). These rapid, unpredictable shifts in the defense posture of the United States call for new and innovative answers to the force structure question.

This thesis will present a new concept of force structure design that relies on estimated force effectiveness and predicted global political conditions to design force structure by scaling the force (size) and balancing the force (unit mix). A recommended force will be derived by optimizing the 'balance' of a force structure, with size as a input constraint. This force structure design process uses a non-linear program to minimize the difference between a constrained force structure and a theoretical best force structure. Optimization of the force design process will provide the user with a basis for understanding the underlying principals of force structure design.

In the past, force designers have generally followed the pattern of adding or subtracting marginal amounts from the existing force structure, based on the budget. Force structure has been designed around a 'hunt and peck' process. Each budget is scrutinized to check on new or politically sensitive items, and to get 'the most for the money'. The resulting force structure is a mishmash of older, stable systems that have won longstanding support (aircraft carriers, marine divisions) and new technology items trying to break in (stealth technology, starwars, etc).

The effect of this arduous process is that the force structure is not coordinated to produce the best possible force for the situation. Because of the political sensitivities (for example, deactivating an Army division based in the continental U.S. is next to impossible), the force structure has remained relatively stable. The force capabilities have also remained relatively constant. The changes in budget and global power necessitate an objective review of every element of the force structure. The results of the model can be used as a first step in the upcoming force structure modernization. The force structures generated by this model should be used as starting points for debate, further force effectiveness modelling, wargaming, and cost estimation.

# III. MODEL DEVELOPMENT METHODOLOGY

The development of this model begins with a review of the problem and its objectives. Defining the problem with sufficient detail is the key to developing a systematic model that gives useful output. A clear and concise definition and objective will center the model on the important issues, and decrease the impact of unimportant, or unnecessary constraints. The model will be designed for a specific purpose and provide results based only on the factors that impact directly on the results.

## A. PROBLEM DEFINITION AND OBJECTIVES

The problem is to develop a systematic force design model that uses quantifiable factors to design and compare force structures. The model should be:

- Transparent- must be able to link the input to the output and the output to the input.
- Deterministic- always gives the same output with constant input.
- Deskside- must run on currently available software, on a personal computer.
- Easily understood- the analyst or decision maker must be able to understand the concepts used in the program and must be able to read and understand the output.
- Easy to change- inputs must be user driven (analyst or decision maker) and easily changed.
- Sensitive- provides for a sensitivity analysis of all important inputs by the user (analyst or decision maker).

- Fast- must provide results in less than fifteen minutes of computer time.

## B. FORCE EFFECTIVENESS

Force effectiveness is a combination of several factors. The factors that affect force effectiveness are much debated and difficult to quantify. The factors range from the size and equipment of the unit to leadership and morale. An example of the relative effectiveness of two types of units follows. An aircraft carrier battle group is designed and equipped to be effective in air-to-air combat, strike missions, and force projection; however, it is not designed to hold terrain, or conduct land operations. In contrast, heavy divisions are designed and equipped to hold terrain and conduct land operations, but is unable to conduct air-to-air operations.

The tradeoffs between different force structures are necessary to provide a broad spectrum of options to the United States and its allies in response to global political/military situations. In order to preserve the necessary flexibility in military response, units of different force structure are required. In order to decide what type of force mix is appropriate to meet global conditions, force effectiveness must be measured in some way. This thesis will quantify force effectiveness by using a selected list of attributes. These attributes were chosen to highlight the different capabilities of all forces and to be easily understood. These attributes were developed as an expansion of the U.S. Army's dynamics of combat power; maneuver, firepower, protection and leadership. (FM 100-5, 1986, pp. 11-14) The following is a list of the force attributes as developed for use in this thesis and their definitions:

- Lethality (LETH)- the capability of the unit to produce destructive combat power as determined by the lethality and range of its organic conventional weapons.
- Deployability (DEPL)- the capability of the unit to move with all personnel and equipment over long distances as determined by the type, number, and speed of non-organic transportation required.
- Mobility (MOBL)- the capability of the unit to move with all personnel and equipment in theater or smaller operations as determined by the speed of movement, using organic transportation only.
- Sustainability (SUST)- the capability of the unit to conduct continuous combat operations with organic supply and support units.
- Political Impact (POLI)- the capability of the unit to maintain a combat-ready presence in an area of operations without increasing the political tension in the area.
- Survivability (SURV)- the capability of the unit to withstand determined enemy attack and continue to perform its combat mission.

## C. DESIGN OF THE MODEL

The design of this model is based on the idea of selecting forces (units) to fill requirements. The requirements are generated through a process that starts with a prediction of global conflict and then derives the necessary force attribute mix. Forces are then picked to fill the attribute requirements in an optimal manner.

### 1. MODEL INPUTS

The variables chosen for this thesis are driven by the user. Any description or definition given to a variable in this thesis can be changed or modified. The important aspect of the program is that the idea behind each variable must remain constant. The units used here are division equivalents; however, any size units can be used.

This model can be used to develop both high and low resolution solutions to many force design questions; however, caution must be used to gain the correct interpretation from the model. If inputs are given at high resolution, then results will only be suitable for high resolution study. The same will be true for low resolution inputs and solutions. This thesis will consider a very aggregated level of modeling that will be easily understood.

#### a. Units

An important consideration in the design process is 'What is the size of forces to be modeled?'. The scale of the model must fit the objectives and provide useable results. Force structure can be easily divided without much overlap into several separate categories: strategic verses conventional, active verses reserve, and forward deployed verses contingency.

This model will design only active, conventional force structure and will not differentiate between forward deployed and contingency. For this model to be simple and fast running only large scale units can be used. The model will design force structure with forces of division size or larger. The model will consider only active, deployable units. The actual units modelled can be easily changed and updated without any major reprogramming. The model will use the following units as building blocks of force structure:

- Heavy Divisions (HD)- Army mechanized or tank divisions.
- Light Divisions (LD)- Army airborne, airassault, light, mountain or motorized divisions.
- Marine Divisions (MD)- Marine infantry or tank divisions and supporting ships.
- Aircraft Carrier Battle Groups (AC)- Conventional or nuclear powered aircraft carriers (CV or CVN) with all routinely attached escort and support ships and aircraft.
- Air-to-Air Wings (AA)- Air Force fighter wings.
- Air-to-Ground Wings (AG)- Air Force attack and conventional bomber wings.
- Surface Action Groups (SA)- Navy battleships, heavy cruisers, etc., used as primary combatants not in support of aircraft carriers, including supporting ships.
- Special Forces Groups (SF)- Army special forces groups, Navy Seal squadrons, unconventional warfare units.

The list above is by no means complete in including all of the various force structures now in service with the military forces of the United States. In order to achieve the objectives of speed and simplicity for the model, a very large scale must be used. The units listed are the major players in planning global strategy, and each unit is capable of acting independently during conflict. Each unit also represents a major budget item and as such can be assigned a cost factor that will be used in optimizing the overall force structure.

### b. Global Political/Military Predictions

The probability of conflict in the world is constantly changing. The ability of the United States to prepare for conflict is dependent on its ability to predict where the conflict will occur and at what level of intensity. In order to design the proper mix of units that give a desirable, effective force for any given conflict, a decision must be made regarding what type of force effectiveness is required to win a conflict at a given level of intensity, at a given geographical location. To continue with model development, input parameters for levels of conflict and for force effectiveness at each level must be developed.

#### (1) Levels of Conflict

Much study and debate is currently underway over the naming and defining of levels of conflict. It is known that different levels of conflict will require different types of forces to be effective. For example, in a guerrilla war, the force effectiveness of a heavy division is less than the force effectiveness for a special operations group; however, in a mid- intensity conventional war, a heavy division is much more effective. The levels of conflict used by this model will cover the major levels of conventional warfare. Again, due to the requirement for speed and simplicity, the levels of conflict are aggregated to a relatively high degree. The following is a list of the levels of conflict and their definitions:

- Terrorism (TERROR)- Active terrorist activity, such as bombings, highjackings, and assignations directed against United States forces or friendly governments.
- Guerrilla Warfare/ Insurgency (INSURG)- Active, organized combat by recognized insurgents who desire to overthrow the government.
- Contingency and Limited Objective War (CALOW)- Contingency operations, and small scale military intervention.
- Mid Intensity Warfare (MIDINT)- Operations at theater level, consisting of warfare with all conventional weapons against an enemy state.
- High Intensity Warfare (HIGHINT)- Global warfare, including the use of non-conventional munitions (chemical, biological, and nuclear).

(2) Geographical Areas

Within different geographical areas, force effectiveness will differ even within the same level of conflict. For example, a low intensity conflict in Southwest Asia will require a different force mix than a low intensity conflict in Southeast Asia. Several considerations that drive the differences in force effectiveness in different areas are terrain, distance to resupply, location of United States bases, treaties, political concerns, and weather. Terrain and weather dictate that highly mobile and survivable units would be effective in the mid-intensity conflict concluded in Southwest Asia. A similar mid-intensity conflict in Southeast Asia will require very light units able to move through forest and jungle, as opposed to heavy mechanized units. Any number of geographical areas can be used to develop force structure. This thesis uses the following areas:

- Latin America (LATAM)- Central and South America.
- Africa (AFRICA)- Sub Sarahan Africa.
- Southwest Asia (SWASIA)- India, Pakistan, the Persian Gulf countries.
- Southeast Asia (SEASIA)- China, Australia, Japan, the Pacific rim countries.
- Europe (EUROP)- Europe, including Soviet block and the Mediterranean Sea.

These categories are grouped together to allow aggregation in the geographic locations that are similar in characteristics. Less aggregation is possible with a minor change to the model parameters by the user. The program allows the geographical areas to be grouped in any way (e.g, by climate, terrain, etc). The program can be modified to split areas by climate into arid, semi-arid, temperate, rain forest, etc. Within each area similar conditions must exist to the extent possible.

## 2. FORCE REQUIREMENT GENERATION

The first step of the system is to develop a technique for generating the force requirements as shown in Figure 1. The difficulty in generating a realistic requirement for forces is derived from the fact that it is seldom known beforehand what those forces will be required to do. The process of force requirement generation is a six-step procedure. The steps are:

- Develop a Probability of Conflict Matrix, C(J,K).
- Develop a Consequence Vector, V(J).

- Weight the Consequence Vector to obtain the Weighted Consequence Vector, W(J).
- Develop an Ideal Force matrix, F(I,J).
- Weight the Ideal Force Matrix.
- Generate the Force Attribute Request (FAR).

<u>a. The Probability of Conflict Matrix</u>

The basis for this prediction of the future is a matrix of probabilities that are subjectively derived and are given for

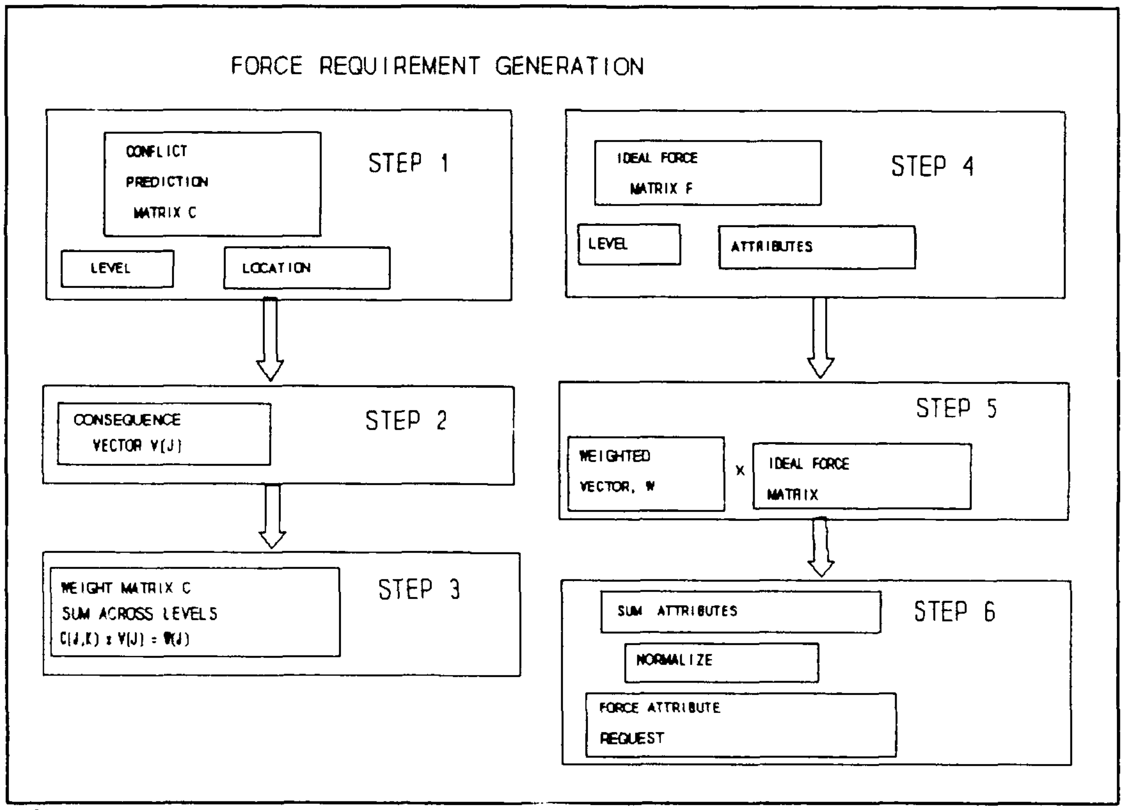


**Figure 1. FORCE REQUIREMENT GENERATION**

each geographical area, for each level of war. The matrix will be referred to as the probability of conflict matrix or matrix C. Matrix C will be a J (levels) by K (locations) will be referred to as the probability of conflict matrix or matrix C. Matrix C will be a J (levels) by K (locations) matrix. An example of a matrix of this type is given in Table 1.

**Table 1. PROBABILITY OF CONFLICT MATRIX- MATRIX C**

| | LOCATION (K) | | |
|---|---|---|---|
| LEVEL | AREA(1) | AREA(K-1) | AREA(K) |
| LEVEL(1) | P{LEVEL(1) given a conflict in AREA(1)} | P{L(1)\|A(K-1)} | P{L(1)\|A(K)} |
| LEVEL(2) | P{L(2)\|A(1)} | P{L(2)\|A(K-1)} | P{L(2)\|A(K)} |
| LEVEL(J-1) | P{L(J-1)\|A(1)} | P{L(J-1) \|A(K-1)} | P{L(J-1) \|A(K)} |
| LEVEL(J) | P{L(J)\|A(1)} | P{L(J)\|A(K-1)} | P{L(J)\|A(K)} |

The elements of this matrix C(J,K) represent the probability that a Level J conflict occurs, given that a conflict occurs in Area K. In other words, this is a measurement of the probability that a certain level of conflict will occur in a area, given that a conflict does occur. This model makes the following assumptions based on the construction of Matrix C:

- A conflict of some type will occur in each area. Each column will sum to one. This assumption is desired to allow the levels of conflict to be the factor that drives force requirement generation, not location of the conflict.

- All conflicts of similar levels will require similar force structure to win, regardless of the location. The level of conflict is the main factor in deciding force mix. A low intensity conflict will require light, mobile forces whether it is in the jungle, desert or arctic. Similarly, high intensity conflict requires survivable, lethal units to win in any terrain.

The assumptions given will help clarify the process of force requirement generation. This thesis will consider the sum of rows J as a comparison to the well known idea of the spectrum of conflict (See Figure 2.). The lower the level of conflict in intensity, the greater the probability of its occurrence. Also, the higher the intensity (and the risk), the lower the probability of its occurrence.

b. The Consequence Vectors

The next step of force requirement generation is to weight the levels of conflict to reflect the destructive consequence, or risk, of each level. A low intensity conflict such as a terrorist campaign will require less in resources to win and will cause less damage if we lose than a high intensity war. The lower level of conflict will generate less risk to the United States. The procedure for weighting the levels of conflict is to use a vector to multiply each sum across the levels. The vector is called the consequence vector V(J). The consequence vector can be constructed in any way desired by the user that provides for appropriate weights. One example of a weighting method is to weight the lowest level as 1.0, and develop the other weights from a subjective assessment of the consequences of the lowest level.

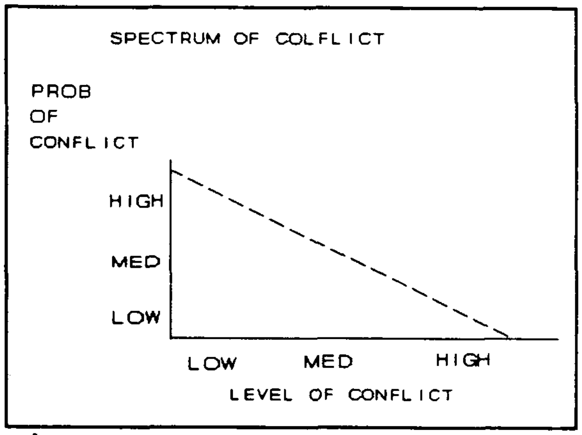


**Figure 2. SPECTRUM OF CONFLICT**

the levels of conflict is to use a vector to multiply each sum across the levels. The vector is called the consequence vector V(J). The consequence vector can be constructed in any way desired by the user that provides for appropriate weights. One example of a weighting method is to weight the lowest level as 1.0, and develop the other weights from a subjective assessment of the consequences of the lowest level. All other weights will be higher than 1.0. Another method weights the highest level as 1.0, and develops the other weights from a subjective assessment of the fraction of 1.0 that is representative of their consequences. The process of developing force requirements is very sensitive to the weighting of each level. The preferred weighting is done using fractions. An example of the sum of levels and the weighting of the levels follows in Table 2.

**Table 2. CONSEQUENCE VECTOR**

| LEVELS | WEIGHTS |
|---|---|
| LEVEL (1) | C(1) |
| LEVEL (2) | C(2) |
| LEVEL (J-1) | C(J-1) |
| LEVEL (J) | C(J) |

The consequence vector provides the user with the ability to change the preference of force effectiveness attributes based on the assessment of risk. Each level of conflict has an assumption of risk. The force structure design that is produced by this model will be tailored to the user's assumption of that risk.

### c. Weighting the Consequence Vector.

The method of weighting is by multiplication. Each weight V(J) is multiplied by the sum across the Level(J). This will create another vector W(J), the weighted conflict prediction vector. An example of the process to derive vector W is given in Tables 3 and 4. The sum(J) column is the spectrum of conflict that the user has chosen to describe the probability of conflict at each level.

**Table 3. EXAMPLE OF FINDING WEIGHTED CONSEQUENCE VECTOR ,W.**

Given: Matrix C(J,K)

| AREAS(K) | | | | | |
|---|---|---|---|---|---|
| LEVELS(J) | WEST | EAST | NORTH | SOUTH | SUM(J) |
| LOW | 0.70 | 0.40 | 0.65 | 0.80 | 2.55 |
| MID | 0.20 | 0.40 | 0.30 | 0.15 | 1.05 |
| HIGH | 0.10 | 0.20 | 0.05 | 0.05 | 0.40 |
| SUM(K) | 1.0 | 1.0 | 1.0 | 1.0 | 4.0 |

The next step is to weight each element of the sum(J) by the appropriate element of the consequence vector V(J).

**Table 4. WEIGHTED VECTOR EXAMPLE (CONT).**

Given: Vector C(J)

| LEVELS(J) | SUM(J) | X | C(J) | W(J) |
|---|---|---|---|---|
| LOW | 2.55 | X | 0.10 | 0.255 |
| MID | 1.05 | X | 0.30 | 0.315 |
| HIGH | 0.40 | X | 1.00 | 0.40 |

The weighted consequence vector, W(J), now reflects the fact that even though a low level of conflict is more probable, the consequences of higher levels of conflict are such that more emphasis must be given to the attributes that will win a high level of conflict. This completes the first stage of force requirement generation.

### d. The Ideal Force Matrix

The next step of force requirement generation is to develop a force mix that will be the most effective in fighting each level of conflict. This will be a matrix of attributes and levels; an I by J matrix. This matrix is the Ideal Force Matrix-(Matrix F). An example of Matrix F is shown in Table 5.

**Table 5. IDEAL FORCE MATRIX- MATRIX F**

| | LEVELS | | |
|---|---|---|---|
| ATTRIBUTES | LEVEL(1)LOW | LEVEL(2)MID | LEVEL(J)HIGH |
| ATT(1) LETHALITY | % of ATT(1) for best force in LEVEL(1) | % of ATT(1) for best force in LEVEL(2) | % of ATT(1) for best force in LEVEL(J) |
| ATT(2) MOBILITY | % of ATT(2) for best force in LEVEL(1) | % of ATT(2) for best force in LEVEL(2) | % of ATT(2) for best force in LEVEL(J) |
| ATT(I) SUSTAIN-ABILITY | % of ATT(I) for best force in LEVEL(1) | % of ATT(I) for best force in LEVEL(2) | % of ATT(I) for best force in LEVEL(J) |
| SUM(J) | 100% | 100% | 100% |

The elements of this matrix F(I,J) represent the theoretically best possible percentage of force attribute (I) to have in a conflict at level (J), which summarizes the best force mix to employ at each level of conflict. This ideal force matrix is a subjective assessment of what force would be effective in each level of conflict. The following assumptions are made by the construction of the Ideal Force Matrix:

- Force effectiveness attributes are quantifiable, and are meaningful in describing force effectiveness.
- Different levels of conflict require different force effectiveness attributes to win.
- Force effectiveness attributes can be weighted and summed without causing a disturbance in the underlying principal that force effectiveness is measured by force effectiveness attributes.

e. Weighting the Force Matrix

The next step is weighting the Ideal Force Matrix, F(I,J), with the weighted consequence vector, W(J). In this step, each element of the Ideal Force Matrix, F(I,J) is weighted by multiplication with the corresponding (J) element of the weighted consequence vector, W(J). An example is given in Tables 6 through 9.

**Table 6. EXAMPLE OF AN IDEAL FORCE MATRIX F(I,J).**

Given: Matrix F(I,J).

| | LEVEL(J) | | |
|---|---|---|---|
| ATT(I) | J(1)LOW | J(2)MID | J(3)HIGH |
| ATT(1) LETHALITY | 0.10 | 0.50 | 0.70 |
| ATT(2) MOBILITY | 0.60 | 0.40 | 0.10 |
| ATT(3)SUSTAINABILITY | 0.30 | 0.10 | 0.20 |
| | 1.00 | 1.00 | 1.00 |

**Table 7. WEIGHTED CONSEQUENCE VECTOR, W(J).**

Given: Vector W(J).

| LEVEL | WEIGHTS, from Table 4. |
|---|---|
| LOW, W(1) | 0.255 |
| MID, W(2) | 0.315 |
| HIGH, W(3) | 0.400 |

Table 8. WEIGHTING OF THE IDEAL FORCE MATRIX F(I,J).

| | LEVEL(J) | | | |
|---|---|---|---|---|
| ATT(I) | J(1)LOW | J(2)MID | J(3)HIGH | SUM(I) |
| ATT(1) LETHALITY | W(1)xF(1,1) 0.10 x .255 = .0255 | W(2)XF(1,2) .50 x .315 = .1575 | W(3)XF(1,3) 0.70 x .40 = .2800 | 0.463 |
| ATT(2) MOBILITY | W(1)XF(2,1) 0.60 x .255 = .1530 | W(2)XF(2,2) 0.40 x .315 = .1260 | W(3)XF(2,3) 0.10 x .40 = .0400 | 0.319 |
| ATT(3) SUSTAIN-ABILITY | W(1)XF(3,1) 0.30 x .255 = .0765 | W(2)XF(3,2) 0.10 x .315 = .0315 | W(3)XF(3,3) 0.20 x .40 = .0800 | 0.188 |

Each element of the F(I,J) matrix is weighted according to the level of conflict that it describes. The resulting weighted matrix is still scaled within each column, but each column is weighted differently to reflect the element of risk associated with each level of conflict.

### f. The Force Attribute Request (FAR)

The sum(I) of the rows is a dimensionless number that represents an 'amount' of each attribute needed to have an ideal force, given the weighting system. The idea of an 'amount' of an attribute will not be used to develop the force requirement because additive properties of attributes are most likely not linear. For example, is twice as much lethality twice as effective? In order to skirt this issue and still provide a meaningful result, this thesis uses the 'amounts' of the attributes to develop a percentage for the best possible force. By normalizing the 'amounts' of the attributes, a desired percentage of each attribute will be derived. This percentage will represent the correctly balanced force mix, as described by the force effectiveness attributes. The final step of the force requirement generation is to normalize the sum(I) of the weighted F(I,J) matrix. This will form the Force Attribute Request or FAR(I) Vector. An example of this last step is shown in Table 9.

**Table 9. GENERATING THE FAR(I) VECTOR**

| ATTRIBUTE(I) | SUM(I), from Table 8. | Normalized FAR(I) |
|---|---|---|
| ATT(1) LETH | 0.463 | 0.48 |
| ATT(2) MOBL | 0.319 | 0.33 |
| ATT(3) SUST | 0.188 | 0.19 |

The FAR(I) vector represents the percentage of each attribute that will be required to have a balanced force.

# IV. MODEL FORMULATION

## A. MODEL DESIGN

The model is composed of three parts: a data file, a FORTRAN program and a GAMS program. (see Figure 3.)

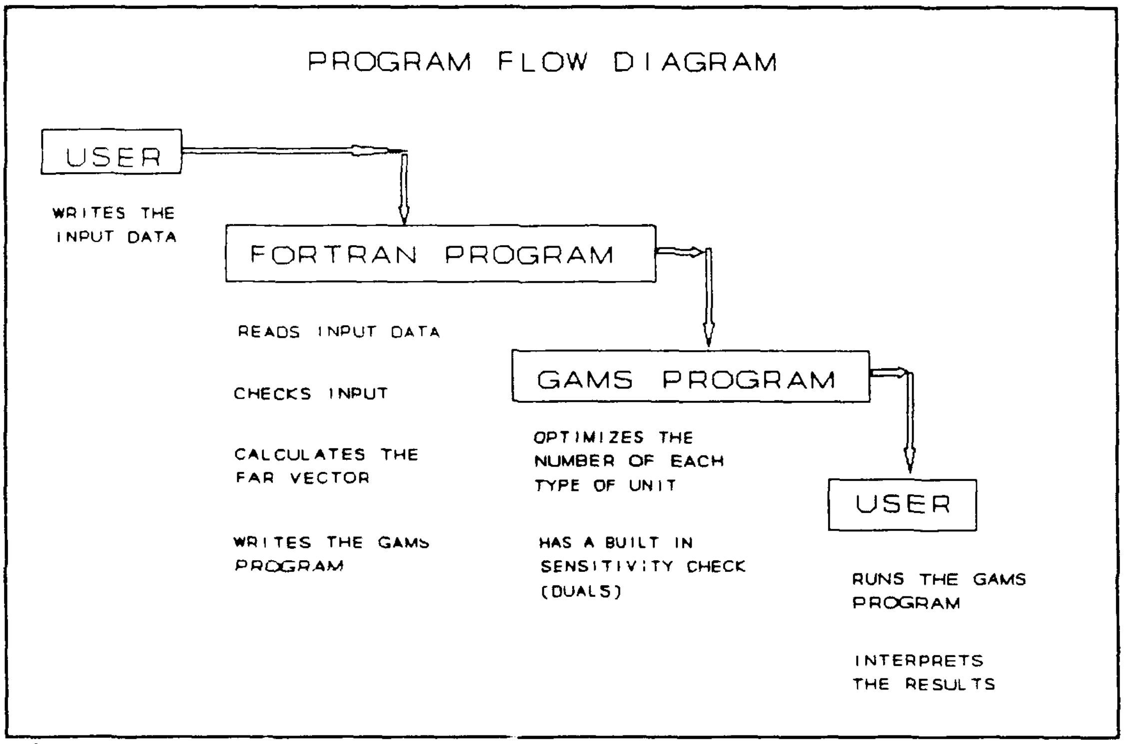


**Figure 3. PROGRAM FLOW**

The FORTRAN program code is given in Appendix A. The user must enter and edit the required data elements in the data file prior to executing the program. An example of a data file for a base case scenario is at Appendix B.

The FORTRAN program will check each element to ensure the value is within the model constraints. Error messages will appear if any value is not within the required tolerance. The FORTRAN program then generates data for a GAMS program and writes the GAMS code that will optimally solve the problem. The GAMS program uses the zero/one Optimization Method (ZOOM) to solve the relaxed mixed integer problem. An example of a GAMS program that was generated by a base case data scenario is given in Appendix C. The user must execute the GAMS program and interpret the results from a listing file. An example of a GAMS listing file is located in Appendix D. As a time saving option a FORTRAN program such as PROGRAM READIT, located in Appendix E, may be used to rapidly observe the results of each program run.

## B. RELAXED MIXED INTEGER PROGRAM MODEL FORMULATION

The force structure optimization model requires the following:

Indices:

| | |
|---|---|
| i = 1,....,I | Attributes |
| u = 1,....,U | Units |

Data:

| | |
|---|---|
| Mins(U) | Minimum number of units of type U allowable. |
| Maxes(U) | Maximum number of units of type U allowable. |
| F(I,U) | Unit effectiveness matrix. |
| FAR(I) | Force Attribute Request. |
| Size | Total number of units. |

Variables:

| | |
|---|---|
| X(U) | Optimum number of Units of type U. |
| Z | Maximum Deviation. |

The objective value Z is a real number. Z is the maximum absolute difference between two vectors of attributes. Each vector is defined and interpreted as follows:

- Requested Attribute Vector(I)- the product of the FAR(I) vector and the scalar SIZE. This vector represents the EXACT force attribute mix, in both size and percentage, that the program determines to be optimal. In other words, the program will select a force mix with the number of units = SIZE, with each unit having the same force attributes as the FAR(I) vector.

- Delivered Attribute Vector(I)- the product of the Force Effectiveness Matrix F(U,I) and the solution X(U). This vector represents the best possible mix of units, under the constrains of MINS and MAXES, to match the Requested Attribute Vector.

The program determines the optimal solution in an iterative process that attempts to match the Requested Attribute Vector exactly. Tables 10, 11, and 12 illustrate the process of determining Z and finding the optimal solution.

**Table 10. THE REQUESTED ATTRIBUTE VECTOR**

| GIVEN:<br>FAR(I)<br>and SIZE | REQUESTED ATTRIBUTE<br>VECTOR =<br>FAR(I) * SIZE |
|---|---|
| LETH 0.40<br>DEPL 0.25<br>MOBL 0.35 | 0.40*10=4.00<br>0.25*10=2.50<br>0.35*10=3.50 |
| SIZE = 10 | |

**Table 11. THE DELIVERED ATTRIBUTE VECTOR**

| GIVEN:<br>SOLUTION X(U)<br>AND MATRIX F | | DELIVERED ATTRIBUTES: LETH 3.15<br>DEPL 2.70<br>MOBL 4.10 |
|---|---|---|
| SOLUTION;X(U)<br>HD 3<br>LD 2<br>AC 5<br>SIZE=10 | MATRIX F<br>LETH DEPL MOBL<br>HD .45 .05 .50<br>LD .15 .55 .30<br>AC .30 .30 .40 | LETH DEPL MOBL<br>3*.45=1.35 3*.05= .15 3*.50=1.50<br>2*.15= .30 2*.55=1.05 2*.30= .60<br>5*.30=1.50 5*.30=1.50 5*.40=2.00<br>SUM 3.15 2.70 4.10 |

**Table 12. THE OBJECTIVE VALUE - Z**

| REQUESTED ATTRIBUTES | DELIVERED ATTRIBUTES | ABSOLUTE DIFFERENCE | Z<br>MAX DIFFERENCE |
|---|---|---|---|
| LETH 4.0<br>DEPL 2.5<br>MOBL 3.0 | 3.15<br>2.70<br>4.10 | .85<br>.20<br>1.10 | 1.10 |

The solution X(U) used for the example problem was chosen arbitrarily only to show the process of how Z is found. The GAMS program iteratively finds the smallest possible Z for all feasible solutions. By finding the smallest possible Z, the program finds the optimal solution, which is a constrained (subject to MINS and MAXES) solution, X(U)*F(U,I), that is the closest to the unconstrained solution, FAR(I)*SIZE.

Formulation:

$$Minimize \sum_{U} Z_u$$

Subject to:

$$X_u \geq MINS_u \forall U \quad (1)$$

$$X_u \leq MAXES_u \forall u \quad (2)$$

$$\sum_{u} X_U \leq SIZE \quad (3)$$

$$\sum_{u} (X_u * (F_{ui} - FAR_i) \leq Z \quad (4)$$

$$\sum_{u} (X_u * (F_{ui} - FAR_i)) \geq -Z \quad (5)$$

In the above formulation, equations (1) and (2) are needed to insure the optimal force meets the minimum and is not above the maximum number of units, for each type of unit. Equation (3) limits the total number of units of all types to an input constraint.Equations (4) and (5) will cause the program to minimize the maximum difference in the requested and delivered force attribute vectors, as demonstrated in Tables 10,11,12.

The solution is optimal when the maximum difference is minimized. Figure 4 presents a graphic representation of the objective function.

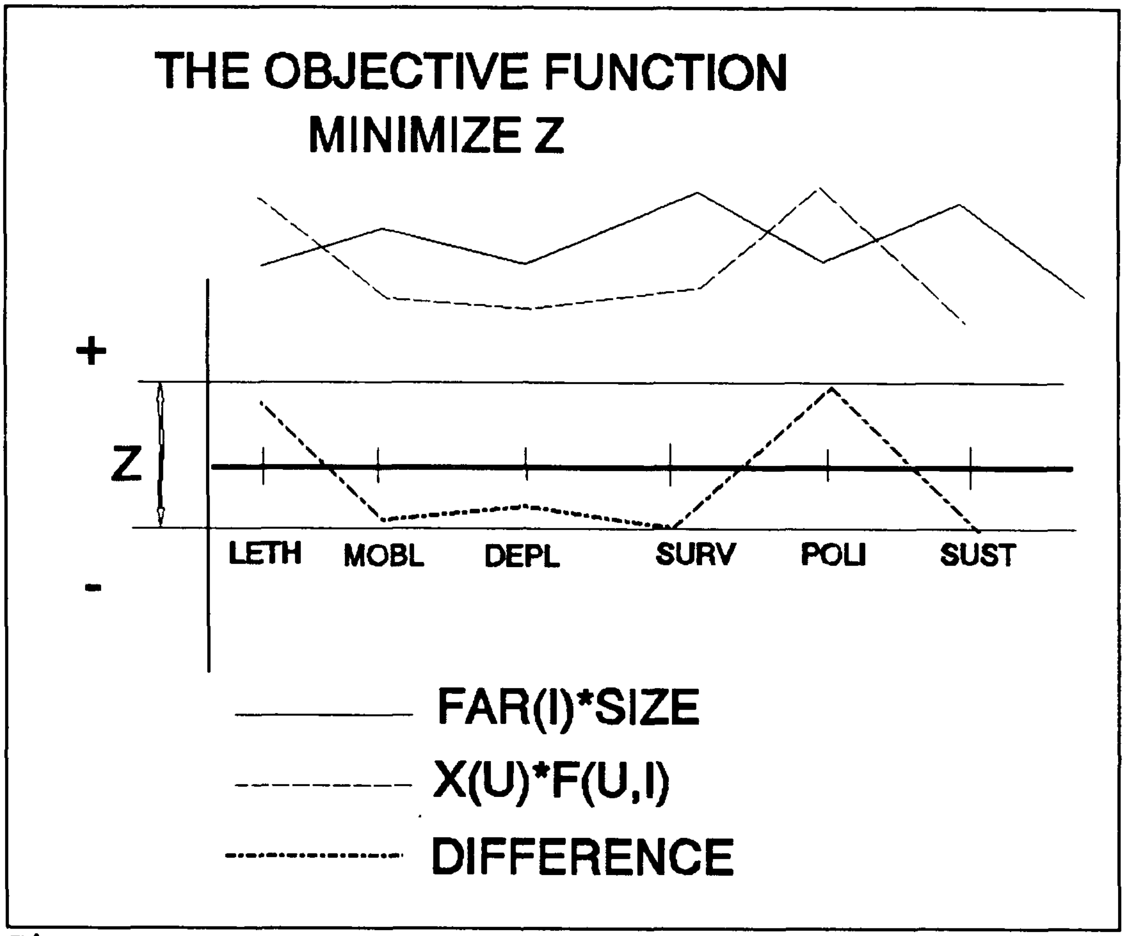


Figure 4. MINIMIZING THE MAXIMUM DIFFERENCE IN VECTORS

# V. ANALYSIS OF ThE MODEL

The model analysis was conducted in three phases. The first step was to determine if the model would give predictable results at some known boundary points. Next, the sensitivity was checked with respect to the input data. Finally, several 'realistic' sets of data were entered corresponding to given scenarios, and results were compared to military judgement predictions.

## A. BOUNDARY CONDITIONS

Several boundary conditions exit in the model due to the formulation. To check the selection of units for boundary conditions, MINS was set to zero, MAXES was set to 100 and SIZE was set to 50. The following is a description of the conditions that were checked with the outcome.

### 1. The FAR(I) VECTOR MATCHES A UNIT VECTOR

A unit's input force effectiveness vector matches exactly with the FAR vector. The program will choose only the unit that has the matching force effectiveness vector. The program will find the unit mix with the lowest difference in vectors. If one unit's vector matches exactly the FAR vector, the difference will be zero. The program will select the unit with the matching vector in the quantity equal to the input size.

2. A FAR(I) VECTOR of ZEROS

The program will select each unit, in some quantity, that has a minimum value for any attribute. At this boundary, the program must select the minimum level for each attribute in order to minimize the outcome overall.

3. A FAR(I) VECTOR of ONES

The program will select each unit, in some quantity, that has an attribute that is a maximum value. At this boundary, the program must select the maximum level for each attribute in order to minimize the outcome overall.

The program functions predictably at each boundary condition described above. The ability of the model to predictably solve problems at the boundary is key to the process of problem solving. In order for the model to have credibility, it has to be recognized as starting on the correct path.

## B. MODEL INPUT SENSITIVITY

This thesis will not attempt to measure the level of sensitivity for each input variable. This model is user driven and the data inputs to it are subjective. The variances in results can be large for the same situation due to the fact that different users will have different inputs for that situation. This model uses standard input value ranges to limit some of the input variance. An example f this is the conflict prediction matrix C(J,K); the sum of probable conflict across its levels must sum to one. This prevents uneven weighting of conflict levels and locations.

The technique for selection of the subjective values is completely user dependent. Various methods exist for obtaining these values that include the Delphi Method, surveys, and the Analytical Hierarchy Process (AHP). The data input for the attribute mix of each unit was generated by a program from the Military Applications Programs Software (MAPS) named SELECT, that uses AHP to derive relative values from pairwise comparison. The data inputs from SELECT are checked for consistency. The data inputs from the SELECT program for the base case scenario force effectiveness matrix F(I,U) are given in Appendix B, Data File.

## C. TEST SCENARIOS

Three scenarios were chosen to be exercised by this procedure. These scenarios will demonstrate the flexibility of the model to be tailored specifically to various force structure design problems. Case 1, force structure development, is a scenario that develops a force structure to fight a medium to high intensity war in southwest Asia. Case 2, force structure rescaling, is a scenario that begins with the current force structure and conflict prediction as inputs. The model will generate the changes to the current force structure that are necessary to maintain the same force balance; but with half of the budget. The last test case, force structure reorientation, will generate a new force structure by removing the threat of Soviet and Warsaw Pact attack in Europe. These test cases are a small sample of the general uses of this model. An analyst, with a knowledge of GAMS, can modify the program to provide answers to many low resolution force structure design problems.

### 1. FORCE STRUCTURE DEVELOPMENT EXAMPLE

The procedure used to develop this scenario begins with a base case of conflict predictions that is a reasonable and impartial estimate of the current situation. The program output from the base case will be compared to output for data that were different only in the conflict predictions in the area of South West Asia. One data input predicted a high probability of high intensity conflict; another input predicted a high probability of low intensity conflict. The results are compared with the base case and are shown in Figure 5. The results of scenario 1 are encouraging. The model results for each type of unit can be interpreted in the following manner:

- The higher probability of high intensity conflict in Southwest Asia causes the model to select more heavy divisions. A higher probability of low intensity conflict in South West Asia causes the model to select less heavy divisions.

- The light divisions, aircraft carriers, marine divisions and air-to-ground wings are unchanged by either an increase or decrease in the intensity of conflict in Southwest Asia. The explanation for this is that the model selected units to change based on the extremes of high and low intensity conflict. At the extremes are the heavy divisions (high intensity) and special forces groups (low intensity), and by changing these two units, the change in total attributes of the force occurred faster.

* marginal changes in surface action groups and air-to-air wings are not consistent with intuitive military judgement. These results can be accounted for by understanding that the model selects the best overall mix of units by minimizing the difference between requested and delivered attributes. A difference in requested and delivered attributes can occur from 'desirable' and 'undesireable' attributes. In the high intensity scenario, an undesirable attribute is political Impact. Both air-to-air wings and surface action groups are rated relatively high in Poltiical Impact, thus they were not selected for the high intensity scenario.

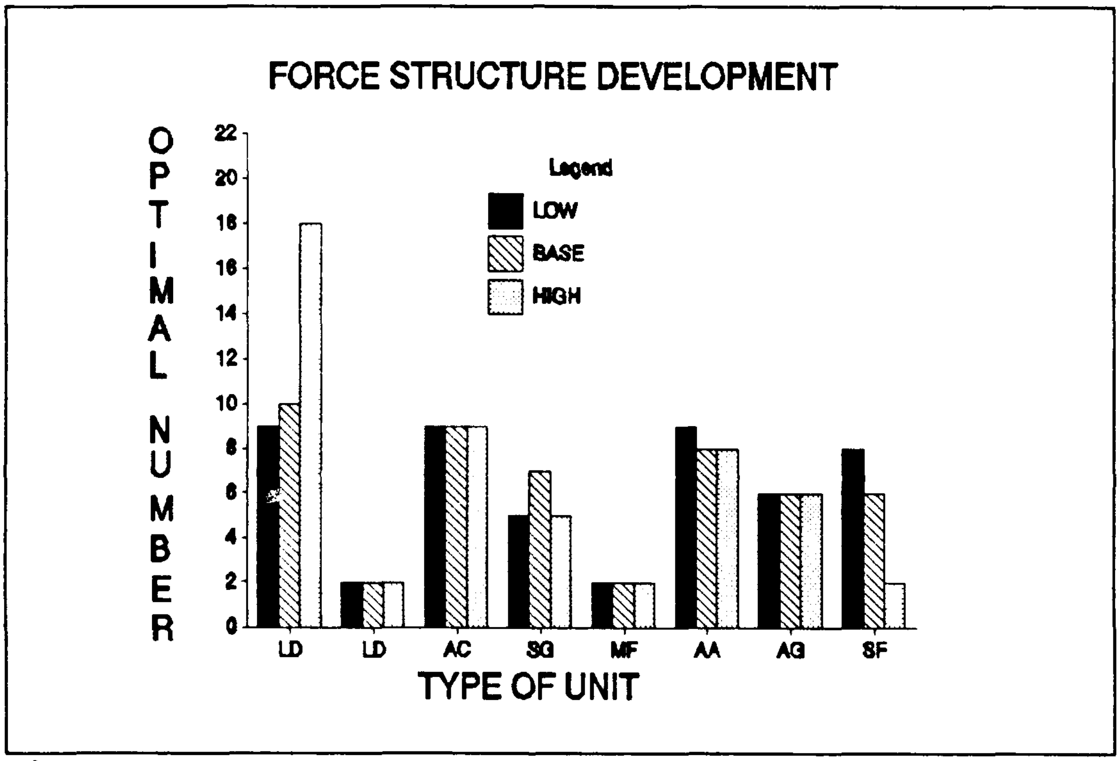


Figure 5. TEST SCENARIO 1

* The change in the number of special forces units from eight for a low intensity conflict to two for a high intensity conflict is consistent with intuitive judgement.

## 2. FORCE STRUCTURE RESCALING EXAMPLE

The procedure for this scenario was to develop a FAR vector based of the current force structure. To do this, the

MAXES(U) and MINS(U) must be set to the current force structure. The program will generate a vector of attributes based on the only solution available, (i.e., the solution that satisfies the input constraints). After the vector of attributes is determined, it is entered directly into the GAMS program. The size constraint will be changed to 75 percent and 50 percent of the current force level. The GAMS program is executed again with the new inputs and constraints with the base case probabilities of conflict.

The results of scenario 2 are shown in Figure 6.

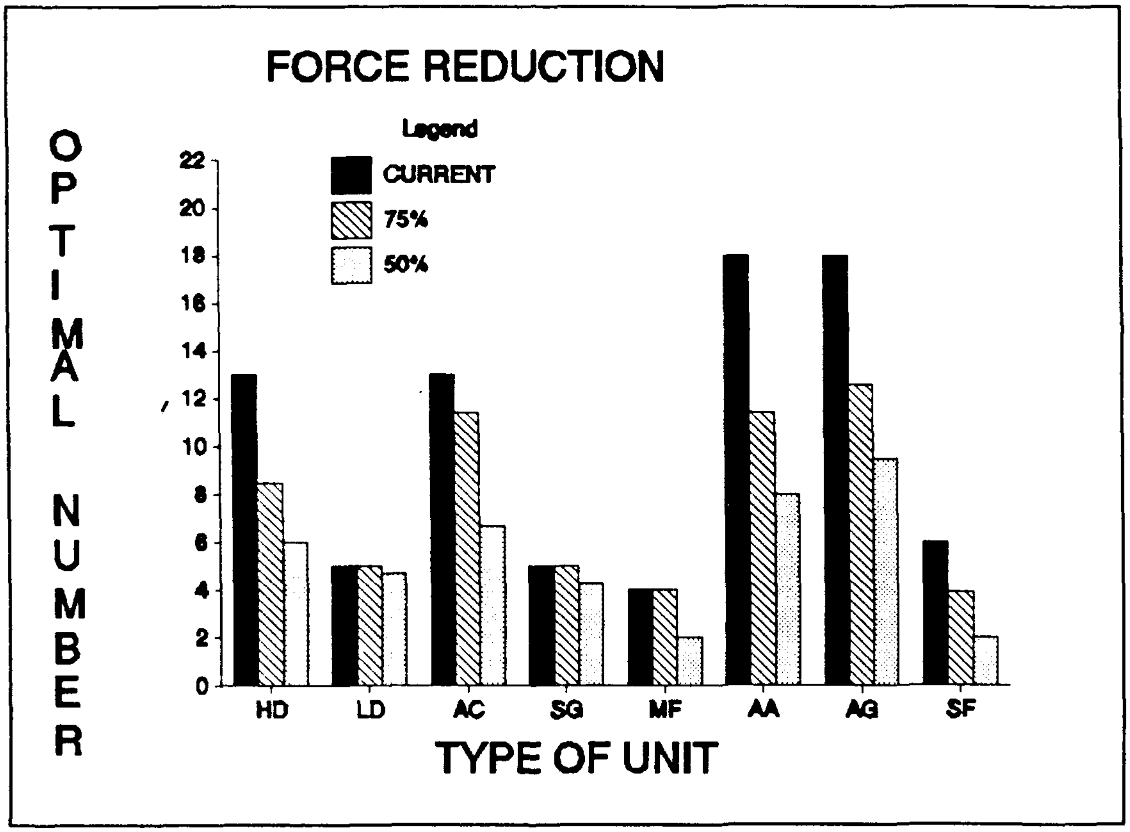


Figure 6. TEST SCENARIO 2

Again the results are consistent with a judgemental solution. The program does not simply reduce each unit by the percentage of reduction (i.e. linear scaling) but rather reduces and adjusts each unit based on its attributes.

The results are shown in Table 13 as the percentage reduction of each unit compared to the percentage reduction for the whole force.

**Table 13. COMPARISON OF UNIT REDUCTIONS FROM FORCE REDUCTION**

| UNIT TYPE | 25% REDUCTION | 50% REDUCTION |
|---|---|---|
| HD | 34% | 53% |
| LD | 0% | 6% |
| AC | 12% | 48% |
| SG | 0% | 14% |
| MF | 0% | 50% |
| AA | 36% | 55% |
| AG | 30% | 47% |
| SF | 18% | 66% |

Table 13 shows the nonlinear aspect of each reduction in units. In order to maintain a force mix at a specified balance of attributes, the program will select the unit to be dropped on the basis of the marginal value of attributes. For a reduction in the number of units the program steps are:

- determine the largest difference in attributes (this will be Z).
- The attribute that has a difference of Z between the Requested and Delivered Attribute Vectors, must be improved. If REQ-DEL is positive, then reduce the unit that has the highest percent of that attribute.

An example of the program steps to reduce units follows: Given the results as shown in Table 12, Chapter IV, where Z=1.10 for the attribute of mobility. The program will select the next unit to reduce based on the best way to reduce Z. To reduce Z, the program will select a force mix with less mobility. As shown in Table 11, the heavy division has the highest percent mobility at 50 percent. By dropping a heavy division, the program will prevent Z from increasing and remain closer to the requested solution. Each iteration of the reduction process considers the tradeoffs between unit attributes in the same manner as described above.

In the results from scenario 2, the units that are reduced fastest and first: HD,AA,AG and SF, are the units with higher percentages of attributes in one area (See Appendix B Data File). These units are designed for a specific mission and are somewhat narrow in their capabilities. The units that are not reduced as fast: LD,AC,SG, and MF are units that have a more even attribute mix. These units are flexible or multi-purpose units. For example, an aircraft carrier can accomplish the missions of air-to-ground and air-to-air wings. As the force is reduced, the all purpose units are retained in higher quantities.

### 3. FORCE REORIENTATION EXAMPLE

This scenario compares a base case scenario of force structure against a force structure derived by changing the probability of conflict matrix. The change in the probability of conflict matrix will reflect a lower probability of high and mid intensity conflict in Europe. This scenario represents the effect of the destabilization of the Warsaw Pact countries and the reduction of the threat of mid or high intensity war.

The results of scenario 3 are shown in Figure 7. The Soviet threat data used were the same data as in the Example 1 base case. In the no Soviet threat data case, the probability of high and mid intensity conflict in Europe was reduced to zero. The removal of the mid and high intensity threat reduces the number of heavy divisions from 10 to 9 and increases the number of special forces groups from 6 to 10.

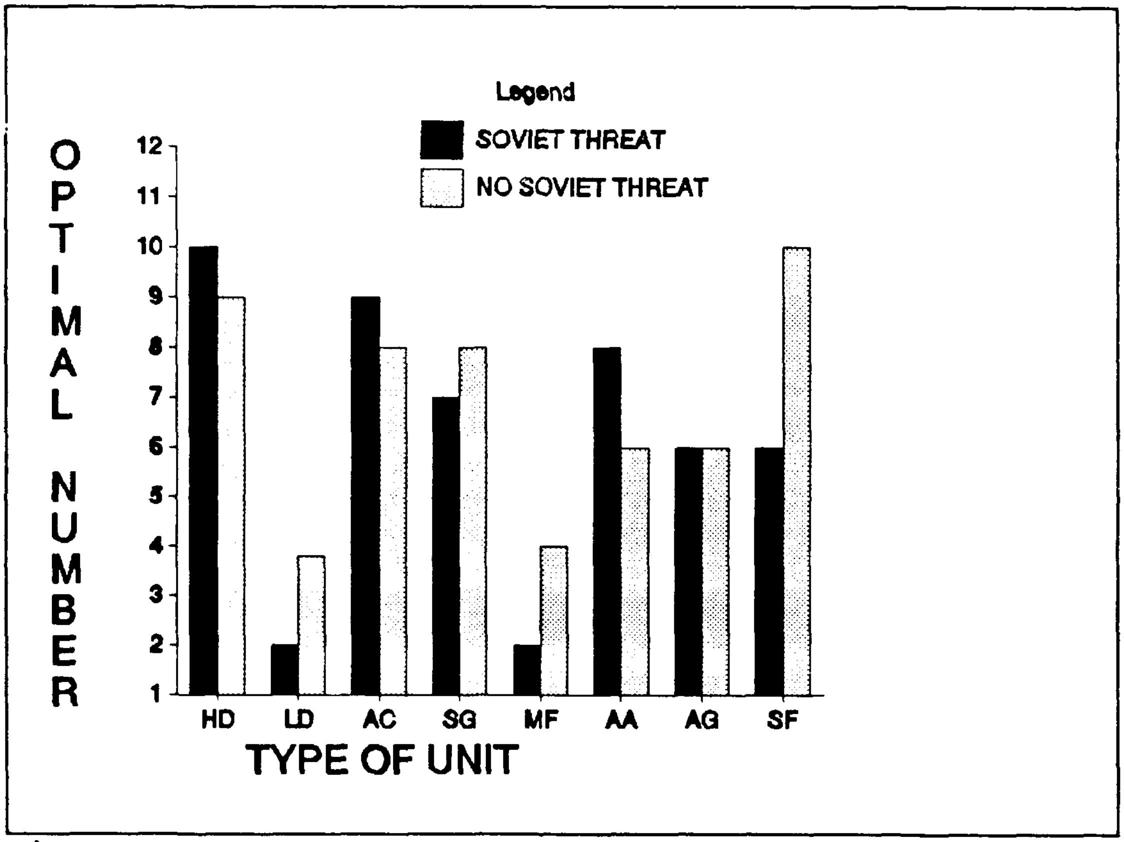


Figure 7. TEST SCENARIO 3

Again, the results seem to be consistent with military judgement. A decrease in the Soviet threat will reduce the number of units that traditionally fight mid and high intensity war: HD,AC,AA. The reduction of units that fight mid and high intensity war also leads to an increase in units that more efficiently fight low intensity war better, such as the light divisions and special forces groups and Marine divisions.

# VI. CONCLUSIONS

This thesis addresses one of the most complicated and important issues of the near future. Force structure design is a topic that has received much attention and debate within political and military circles. The debate is generally centered around how to allocate resources to force structure, not what type of force structure to buy or how to buy it. The procedure currently used to evaluate the conflicting priorities in force structure design is not well defined. The impact of the current force design system in terms of mistakes made, time wasted, and confusion generated is enormous. The system must be improved.

This thesis is a first step to quantify some of the numerous factors that impact on force structure design. A more complete and thorough approach must be seriously undertaken. This analysis demonstrates that the concept of quantifiable, recoverable, and systematic force structure design is possible. The factors such as attributes, the estimates such as consequences and conflict predictions, and the scale of units can be modified to reflect any level of analysis desired. The only limitation to the use of this model is the user's ability to represent the problem in a quantifiable setting.

A relaxed mixed integer programming model to determine the optimal number of each type unit to include in the force structure is proposed. In addition, the model can be used for other analyses involving force structure. Chapter V described three very different uses for the model:

- Force Structure Development - Determine what force mix is needed to face a given threat.
- Force Structure Scaling - Determine what force mix will maintain the current force balance, at a reduced cost.
- Force Structure Reorientation - Determine what force mix is directed toward a specific threat and the impacts of removing the threat on the current force balance.

Future areas for research that are motivated by this thesis are:

- Refining the subjective data input process.
- Further development of the cost function, possibly using accurate dollar figures as costs for each type unit and including the defense budget as a constraint.
- Including a review of the National Military Strategy to insure all missions can be performed by the optimal force, or including the taskings from the NMS as constraints.
- Developing this model to output a multi-year force structure development plan, with additions and removals of units from the current force structure being optimized.

## APPENDIX A FORTRAN PROGRAM CODE

```
      PROGRAM STRUCTURE
*  THIS PROGRAM COMPUTES THE FORCE ATTRIBUTE REQUEST THEN
*  WRITES A GAMS PROGRAM TO OPTIMIZE FORCE STRUCTURE.
*****      XXX = PRINT COMMANDS THAT CAN BE TURNED ON TO *****
          CHECK THE FLOW OF DATA. ERASE THE XXX AND A
*****            PRINTOUT WILL BE PRODUCED OF THE INPUT DATA
*****            ELEMENT.
*
*
*    THIS PROGRAM READS A DATA FILE THAT THE USER HAS
*    PREPARED.  THE NAME OF THE DATA FILE WILL BE ASKED
*    FOR BY THIS PROGRAM.  EDIT THE DATA FILE BEFORE RUNNING
*    THIS PROGRAM.
*
*
***********************************************************
****** THE OUTPUT FILE IS NAMED THE SAME AS YOUR DATA FILE, *
****** EXCEPT IT HAS THE FILE EXTENSION .GMS.  THE OUTPUT   *
****** FILE IS READY TO RUN IN GAMS WITH NO CHANGES.        *
***********************************************************

      CHARACTER FNAME*10,FTYPE(8)*2,
     & ATTRIBUTES(6)*4,FNAME1*14
      REAL C(5), CONFLICT(5,5), IDEAL(6,5),
     & PC(5),FAR(6),CHECK(5)
     & ,CHECK1(5), FORCE(8,6),CHECK2(8),SIZE
      INTEGER I,J,K,MINS(8),MAXES(8)
      SIZE = 55.0

      DATA FTYPE /'HD','LD','AC','SG','MF','AG','AA','SF'/
      DATA ATTRIBUTES/'LETH','DEPL',
       &   'MOBL','SUST','POLI','SURV'/      *
*******************************************************
*  PROMPT USER FOR FILE NAME OF THE DATA FILE
*******************************************************
      WRITE (*,100)
100   FORMAT (' ENTER THE DATA FILENAME:')
```

```
      READ   (*, ' (A)') FNAME
      WRITE (*,160)
160   FORMAT (' ENTER THE GAMS PROGRAM NAME:')
      FNAME1=FNAME//'.GMS'
         WRITE(*,*)FNAME1
101   FORMAT (/////////////////,5F5.1)
      OPEN   (10, FILE = FNAME)
****************************************************
*  READ CONSEQUENCE VECTOR
****************************************************
*
* THIS READS THE FIRST DATA RECORD FOUND *
        READ   (10,101) (C(J),J=1,5)
*******************************************************
*   THIS XXX STATEMENT WILL PRINT A COPY OF THE
*   CONSEQUENCE VECTOR THAT THE PROGRAM READ IN.
*   TO PRINT THE CONSEQUENCE VECTOR, ERASE THE XXX.
*******************************************************
XXX     WRITE  (*,101) C
        DO 88,I=1,5
          C(I)=C(I)*.1
88      CONTINUE

********************************************************
*  READ CONFLICT MATRIX
********************************************************
      DO 1 ,J =1,5
           IF (J.EQ.1)THEN
             READ  (10,102)  (CONFLICT(J,I), I=1,5)
           ELSE
             READ  (10,103)  (CONFLICT(J,I), I=1,5)
           ENDIF
   1     CONTINUE
*******************************************************
*  CHECKING THE CONFLICT MATRIX COLUMNS
*******************************************************
      DO 12,J=1,5
           CHECK(J)=CONFLICT(1,J)
XXX        WRITE(*,*) J,CHECK(J)
           DO 11, I=1,4
             CHECK(J)=CHECK(J)+CONFLICT(I+1,J)
 11      CONTINUE
```

```
XXX     WRITE(*,*) CHECK
        IF(CHECK(J).GT.1.001.OR.CHECK(J).LT.0.999)THEN
        WRITE(*,99)J
 99      FORMAT('COLUMN NUMBER ',I2,' OF THE CONFLICT MATRIX
     &   DOES NOT SUM TO ONE, EDIT YOUR DATA FILE AND RUN
     &   AGAIN'                )
        ENDIF
 12     CONTINUE
102     FORMAT (//////////,T15,5F8.3)
103     FORMAT (T15,5F8.3)
XXX     WRITE  (*,103) ((CONFLICT(I,J),I=1,5),J=1,5)
*
*********************************************
*  READ IDEAL FORCE MATRIX
*********************************************
*
        DO 2, K=1,6
            IF (K.EQ.1)THEN
              READ  (10,104)  (IDEAL(K,I),I=1,5)
            ELSE
              READ  (10,105)  (IDEAL(K,I),I=1,5)
            ENDIF
  2     CONTINUE
************************************************
*  CHECK IDEAL MATRIX COLUMNS
************************************************
       DO 14,J=1,5
            CHECK1(J)=IDEAL(1,J)
XXX         WRITE(*,*) J,CHECK1(J)
            DO 13, I=1,5
              CHECK1(J)=CHECK1(J)+IDEAL(I+1,J)
13     CONTINUE
XXX    WRITE(*,*) CHECK1
       IF(CHECK1(J).GT.1.001.OR.CHECK1(J).LT.0.999)THEN
           WRITE(*,*)'COLUMN NUMBER ',J,' OF THE IDEAL
     &      MATRIX DOES NOT SUM TO ONE, EDIT YOUR DATA FILE
     &      AND RUN AGAIN'
           GOTO 999
       ENDIF
14     CONTINUE
104    FORMAT (/////////////,T18,5F10.3)
105    FORMAT (T18,5F10.3)
```

```
XXX    WRITE (*,105) ((IDEAL(K,I),I=1,5),K=1,6)
****************************************************
*          COMPUTE FORCE ATTRIBUTE REQUEST
****************************************************
        DO 3,I=1,8
           IF(I.EQ.1)THEN
             DO 3, I=1,5
              PC(I)=CONFLICT(I,1)
               DO 31, J=1,4
                PC(I)=PC(I)+CONFLICT(I,J+1)
 31            CONTINUE
  3          CONTINUE
XXX          WRITE(*,*) PC
        DO 4, I=1,5
           PC(I)=C(I)*PC(I)
  4     CONTINUE
XXX     WRITE(*,*) PC
        DO 5, I=1,6
           DO 51, J=1,5
           IDEAL(I,J)=PC(J)*IDEAL(I,J)
 51     CONTINUE
  5     CONTINUE
XXX     WRITE (*,105) ((IDEAL(K,I),I=1,5),K=1,6)
        DO 6, I=1,6
        FAR(I)= IDEAL(I,1)
           DO 61, J=1,4
               FAR(I)=FAR(I)+IDEAL(I,J+1)
 61     CONTINUE
  6     CONTINUE
XXX     WRITE (*,*) FAR
       TOTAL=FAR(1)+FAR(2)+FAR(3)+FAR(4)+FAR(5)+FAR(6)
XXX    WRITE(*,*) TOTAL
       DO 7, I=1,6
          FAR(I)=FAR(I)/TOTAL
  7    CONTINUE
XXX    WRITE(*,*) 'THE FAR VECTOR',FAR

************************************************
* READ MODEL CONSTRAINTS AND INPUTS
************************************************
* READ MINS VECTOR
****************************************************
```

```
        DO 20,I=1,8
           IF(I.EQ.1)THEN
                 READ (10,106) MINS(I)
           ELSE
                 READ (10,107) MINS(I)
           ENDIF
 20     CONTINUE
106     FORMAT (/////////,I2)
107     FORMAT (I2)
XXX      WRITE (*,*) MINS
***************************************************
* READ MAXES VECTOR
*****************************************************
        DO 21,I=1,8
           IF(I.EQ.1)THEN
                 READ (10,108) MAXES(I)
           ELSE
                 READ (10,109) MAXES(I)
           ENDIF
 21     CONTINUE
108     FORMAT (///,I2,T20)
109     FORMAT (I2,T20)
XXX     WRITE (*,*) MAXES
**************************************************
* READ FORCE MATRIX
*****************************************************
       DO 22, K=1,8
           IF (K.EQ.1)THEN
             READ  (10,110)  (FORCE(K,I),I=1,6)
           ELSE
             READ  (10,111)  (FORCE(K,I),I=1,6)
           ENDIF
 22    CONTINUE
110    FORMAT (///////,T9,6F8.4)
111    FORMAT (T9,6F8.4)
XXX    WRITE(*,111)  ((FORCE(K,I),K=1,8),I=1,6)

***********************************************
* CHECK FORCE MATRIX
*********************************************
       DO 23,J=1,8
            CHECK2(J)=FORCE(J,1)
```

```
XXX        WRITE(*,*) J,CHECK2(J)
           DO 231, I=1,6
             CHECK2(J)=CHECK2(J)+FORCE(J,I+1)
231     CONTINUE
        WRITE(*,*) CHECK2
xxx     IF(CHECK2(J).GT.1.001.OR.CHECK2(J).LT.0.999)THEN
xxx         WRITE(*,*)'ROW NUMBER ',J,' OF THE IDEAL MATRIX',
xxx   & ' DOES NOT SUM TO ONE, EDIT YOUR DATA FILE AND RUN
      &    AGAIN'
xxx         GOTO 999
xxx     ENDIF
 23     CONTINUE
*************************************************
* WRITE THE GAMS PROGRAM
****************************************************
        OPEN (20, FILE = fname1)
        WRITE(20,150)
150     FORMAT('$TITLE CHARLES FLETCHER')
        WRITE(20,151)
151     FORMAT('$STITLE FORCE STRUCTURE DECISION AID')
        WRITE(20,199)
        WRITE(20,152)
152     FORMAT('*-GAMS OPTIONS AND DOLLAR CONTROL
      & OPTIONS----*')
        WRITE(20,199)
        WRITE(20,153)
153     FORMAT('$OFFUPPER OFFSYMXREF OFFSYMLIST')
        WRITE(20,199)
        WRITE(20,*) ' OPTIONS LIMCOL=0,LIMROW=0,SOLPRINT=OFF;'
        WRITE(20,*)  ' OPTIONS RESLIM=1000,ITERLIM=10000,
      & OPTCR=0.001;'
        WRITE(20,199)
        WRITE(20,154)
154    FORMAT('*------DEFINITIONS AND DATA-----------------*')
        WRITE(20,*) ' SETS'
        WRITE(20,*) '   U UNITS /HD,LD,AC,SG,MF,AA,AG,SF/'
        WRITE(20,*) '   I ATTRIBUTES /LETH,DEPL,MOBL,
      & SUST,POLI,SURV/   '
        WRITE(20,*) '   REP NUMBER OF REPS   /1*5/        ;'
        WRITE(20,199)
        WRITE(20,*) ' PARAMETERS'
        WRITE(20,199)
```

```
      WRITE(20,200)
      WRITE(20,201) FAR(1)
      WRITE(20,202) FAR(2)
      WRITE(20,203) FAR(3)
      WRITE(20,204) FAR(4)
      WRITE(20,205) FAR(5)
      WRITE(20,206) FAR(6)
199   FORMAT ('                          ')
200   FORMAT (T8,'FAR(I) FORCE ATTRIBUTE REQUEST')
201   FORMAT (T15,'/ LETH ',F8.2)
202   FORMAT (T15,'  DEPL ',F8.2)
203   FORMAT (T15,'  MOBL ',F8.2)
204   FORMAT (T15,'  SUST ',F8.2)
205   FORMAT (T15,'  POLI ',F8.2)
206   FORMAT (T15,'  SURV ',F8.2,'  /')
      WRITE(20,199)
      WRITE(20,207)
      WRITE(20,208) MINS(1)
      WRITE(20,209) MINS(2)
      WRITE(20,210) MINS(3)
      WRITE(20,211) MINS(4)
      WRITE(20,212) MINS(5)
      WRITE(20,213) MINS(6)
      WRITE(20,214) MINS(7)
      WRITE(20,215) MINS(8)
207   FORMAT (T8,'MINS(U) MINIMUM VALUE FOR EACH UNIT')
208   FORMAT (T15,'/ HD ',I2)
209   FORMAT (T15,'  LD ',I2)
210   FORMAT (T15,'  AC ',I2)
211   FORMAT (T15,'  SG ',I2)
212   FORMAT (T15,'  MF ',I2)
213   FORMAT (T15,'  AG ',I2)
214   FORMAT (T15,'  AA ',I2)
215   FORMAT (T15,'  SF ',I2,'  /')
      WRITE(20,199)
      WRITE(20,216)
      WRITE(20,217) MAXES(1)
      WRITE(20,218) MAXES(2)
      WRITE(20,219) MAXES(3)
      WRITE(20,220) MAXES(4)
      WRITE(20,221) MAXES(5)
      WRITE(20,222) MAXES(6)
```

```
      WRITE(20,223) MAXES(7)
      WRITE(20,224) MAXES(8)
216   FORMAT (T8,'MAXES(U) MAXIMUM VALUE FOR EACH UNIT')
217   FORMAT (T15,'/ HD ',I2)
218   FORMAT (T15,'  LD ',I2)
219   FORMAT (T15,'  AC ',I2)
220   FORMAT (T15,'  SG ',I2)
221   FORMAT (T15,'  MF ',I2)
222   FORMAT (T15,'  AG ',I2)
223   FORMAT (T15,'  AA ',I2)
224   FORMAT (T15,'  SF ',I2,'  / ;')
      WRITE(20,199)
      WRITE(20,*)'SCALAR      SIZE      ;'
      WRITE(20,*)'SIZE = ',SIZE,'       ;'
      WRITE(20,199)
      WRITE(20,155)
155  FORMAT('*----UNIT ATTRIBUTE WEIGHT TABLE-----------*')
      WRITE(20,*)'    TABLE'
      WRITE(20,*)'    F(U,I)  FORCE MATRIX'
      WRITE(20,225)ATTRIBUTES
 24   CONTINUE
225   FORMAT(T5,6A8)
      DO 25, I=1,8
      IF(I.LE.7)THEN
         WRITE(20,226)FTYPE(I),(FORCE(I,J),J=1,6)
      ELSE
         WRITE(20,227)FTYPE(I),(FORCE(I,J),J=1,6)
      ENDIF
 25   CONTINUE
226   FORMAT(A2,2X,6F8.5)
227   FORMAT(A2,2X,6F8.5,'    ;')
      WRITE(20,199)
      WRITE(20,156)
156  FORMAT('*-----------MODEL------------------------*')
      WRITE(20,199)
      WRITE(20,*)'VARIABLE'
      WRITE(20,*)'   MAXDEV    MINIMIZE MAX DEVIATION        '
      WRITE(20,*)'   Z         MAXIMUM DEVIATION             '
      WRITE(20,*)'   R(I)      TOTAL ATTRIBUTES REQUESTED    '
      WRITE(20,*)'   R1(I)     TOTAL ATTRIBUTES DELIVERED    '
      WRITE(20,*)'   R2(I)     REQUESTED - DELIVERED         '
      WRITE(20,*)'   R3(I)     SQUARED DIFFERENCES           '
```

```
      WRITE(20,*)'   R4        TOTAL SQUARED DIFFERENCES   '
      WRITE(20,*)'   POWER     SUM OF DELIVERED ATTRIBUTES;'
      WRITE(20,*)'INTEGER VARIABLE'
      WRITE(20,*)'   X(U)      OPTIMUM NUMBER OF UNITS    ;'
      WRITE(20,*)'EQUATIONS'
      WRITE(20,*)'    UPPER(I)   UPPER LIMIT OF DEVIATION'
      WRITE(20,*)'    LOWER(I)   LOWER LIMIT OF DEVIATION'
      WRITE(20,*)'    OBJ  MINIMIZE THE MAXIMUM DEVIATION'
      WRITE(20,*)'  MINIMUM(U) OBSERVE MIN NUMBER OF UNITS'
      WRITE(20,*)'  MAXIMUM(U) OBSERVE MAX NUMBER OF UNITS '
      WRITE(20,*)'  STRENGTH   ESTIMATE FORCE SIZE        '
      WRITE(20,*)'  ROLLUP(I)  FIND REQUESTED DIFFERENCES '
      WRITE(20,*)' ROLLUP1(I) FIND DELIVERED DIFFERENCES  ;'
      WRITE(20,199)
      WRITE(20,157)
157  FORMAT('*------------MINIMIZE-------------------*' )
      WRITE(20,199)
      WRITE(20,*)'  OBJ..   MAXDEV =E= Z               ;'
      WRITE(20,199)
      WRITE(20,158)
158  FORMAT('*--------SUBJECT TO---------------------*' )
      WRITE(20,199)
      WRITE(20,*)'UPPER(I)..SUM(U,X(U)*(F(U,I)-FAR(I))) =L=
     & Z;'
      WRITE(20,*)'LOWER(I)..SUM(U,X(U)*(F(U,I)-FAR(I))) =G=
     & -Z;'
      WRITE(20,*)'  STRENGTH.. SIZE    =L=   SUM(U,X(U))  ;'
      WRITE(20,*)'  MINIMUM(U)..  X(U) =G=   MINS(U)      ;'
      WRITE(20,*)'  MAXIMUM(U)..  X(U) =L=   MAXES(U)    ;'
      WRITE(20,*)' ROLLUP(I)..  SUM(U,FAR(I)*X(U)) =E= R(I)
     & ;'
      WRITE(20,*)'  ROLLUP1(I)..  SUM(U,X(U)*F(U,I)) =E=
     & R1(I)       ;'
      WRITE(20,199)
      WRITE(20,*)'  MODEL FAR10  /ALL/'
      WRITE(20,159)
159   FORMAT('*-----------LOOP-------------')
      WRITE(20,*)'SOLVE FAR10 USING RMIP MINIMIZING MAXDEV
     & ;'
      WRITE(20,*)'  OPTION X:4:0:1    ;'
      WRITE(20,*)'  DISPLAY X.L       ;'
      WRITE(20,*)'  OPTION FAR:4:0:1  ;'
```

```
      WRITE(20,*)'  DISPLAY FAR        ;'
      WRITE(20,*)'  OPTION R:4:0:1     ;'
      WRITE(20,*)'  OPTION R1:4:0:1    ;'
      WRITE(20,*)'  OPTION R2:4:0:1    ;'
      WRITE(20,*)'  DISPLAY R.L        ;'
      WRITE(20,*)'  DISPLAY R1.L       ;'
      WRITE(20,*)'  POWER.L = SUM(I,R1.L(I))     ;'
      WRITE(20,*)'  OPTION POWER:4:0:1;'
      WRITE(20,*)'  DISPLAY POWER.L    ;'
      WRITE(20,*)'  R2.L(I) = R.L(I)-R1.L(I)     ;'
      WRITE(20,*)'  DISPLAY R2.L       ;'
      WRITE(20,*)'  R3.L(I) = SQR(R2.L(I))       ;'
      WRITE(20,*)'  OPTION R3:4:0:1    ;'
      WRITE(20,*)'  DISPLAY R3.L       ;'
      WRITE(20,*)'  R4.L = SUM(I,R3.L(I))        ;'
      WRITE(20,*)'  OPTION R4:4:0:1    ;'
      WRITE(20,*)'  DISPLAY R4.L       ;'
999   CONTINUE
      STOP
      END
```

## APPENDIX B DATA FILE

```
 *  THIS DATA FILE IS USED WITH THE FORTRAN PROGRAM
*  'STRUCTURE' TO ASSIST IN DEVELOPING A FORCE STRUCTURE.
*  BE CAREFUL WHEN CHANGING THIS DATA FILE TO FOLLOW THE
*  COMMENTS FOR FORMATING, THE FORTRAN PROGRAM WILL NOT
*  BE ABLE TO READ CORRECTLY IF A MISTAKE IS MADE.       **
************************************************************
*  INPUT THE FORCE ATTRIBUTE REQUEST VARIABLES
************************************************************
*  THE FIRST ENTRY IS 'CONSEQUENCES'.  THIS IS A VECTOR OF
*  WEIGHTS THAT IS ASSIGNED TO EACH LEVEL OF CONFLICT.  THE *
*  WEIGHT IS  A  REFLECTION OF THE RISK TO THE UNITED STATES
*  OF NOT BEING FULLY PREPARED FOR THE LEVEL OF CONFLICT.
*  ENTER REALS ONLY IN THE FOLLOWING FORMAT:  FORMAT 5F5.1
*
*****************CONSEQUENCES*******************************
*TERRORISM,GUERRILA,LOW INTENSITY,MID INTENSITY,HIGH INTENSITY
0.10  0.15 0.2  0.4  1.0
************************************************************
*
*  THE NEXT INPUT IS THE LEVEL OF CONFLICT PREDICTION.
*  THERE ARE 5 REGIONS OF THE WORLD TO CONSIDER.
*  ASSUME THAT A CONFLICT WILL OCCUR IN EACH REGION WITH A
*  PROB OF 1.
*  THE NUMBER ENTERED IS THE PROBABILITY THAT THE CONFLICT
*  WILL OCCUR AT THE LEVEL INDICATED.
*  ENTER REALS ONLY IN THE FOLLOWING FORMAT: 5F8.6
********LEVEL OF CONFLICT PREDICTIONS***********************
*              LATAM   AFRICA  SWASIA  SEASIA  EUROPE
TERRORISM      0.6     0.4     0.4     0.3     0.02
INSURG         0.2     0.3     0.1     0.4     0.1
CALOW          0.2     0.2     0.2     0.1     0.15
MID INTENSITY  0.0     0.09    0.25    0.18    0.7
HIGH INTENSITY 0.0     0.01    0.05    0.02    0.03
*           ****  NOTICE EACH COLUMN SUMS TO ONE  ****
** IF A COLUMN DOES NOT SUM TO ONE IT WILL WEIGHT THE   ****
** REGION MORE(SUM OVER 1) OR LESS(SUM LESS THAN 1) THAN****
** THE OTHER REGIONS.                                   ****
*
```

```
*   GIVEN A CONFLICT LEVEL, NOW CHOOSE AMONG THE SIX
*   FORCE ATTRIBUTES TO CREATE THE MOST EFFECTIVE
*   FORCE FOR THAT LEVEL OF CONFLICT.  CONSIDER THAT EACH
*   ATTRIBUTE CONTRIBUTES A PERCENTAGE TO THE OVERALL
*   FORCE EFFECTIVENESS.
*                              LEVELS OF CONFLICT
*          TERRORISM    INSURG    CALOW    MID INT   HIGH INT
*ATTRIBUTES
LETHALITY         0.05       0.05      0.15      0.25      0.40
DEPLOYABILITY     0.19       0.2       0.20      0.10      0.05
MOBILITY          0.20       0.25      0.25      0.30      0.20
SUSTAINABILITY    0.01       0.15      0.15      0.15      0.15
POLITICAL         0.50       0.30      0.15      0.05      0.05
SURVIVABILITY     0.05       0.05      0.10      0.15      0.15
*                 ****   NOTICE THE COLUMNS SUM TO ONE    ****
*   IF THE COLUMNS DO NOT SUM TO ONE AN ADDITIONAL WEIGHT
*   FACTOR  WILL BE ADDED.
************************************************************
*      INPUT THE MODEL CONSTRAINTS
************************************************************
*
*  INPUT THE MINIMUM ALLOWABLE STRENGTH FOR EACH FORCE TYPE
*  ENTER INTEGER NUMBERS ONLY IN THE FIRST TWO COLUMNS
8    - HEAVY DIVISION (HD)
2    - LIGHT DIVISION (LD)
8    - AIRCRAFT CARRIER BATTLE GROUP (AC)
4    - SURFACE ACTION GROUP (SG)
2    - MARINE AMPHIBIOUS FORCE  (MF)
6    - AIR TO GROUND WING  (AA)
6    - AIR TO AIR WING  (AG)
2    - SPECIAL FORCES GROUP  (SF)
************************************************************
************
*  INPUT THE MAXIMUM ALLOWABLE STRENGTH FOR EACH FORCE TYPE
*  ENTER INTEGER NUMBERS ONLY IN THE FIRST TWO COLUMNS
16   - HEAVY DIVISION (HD)
 6   - LIGHT DIVISION (LD)
14   - AIRCRAFT CARRIER BATTLE GROUP (AC)
 8   - SURFACE ACTION GROUP  (SG)
 4   - MARINE AMPHIBOUS FORCE (MF)
18   - AIR TO GROUND WING (AG)
18   - AIR TO AIR WING (AA)
```

10 - SPECIAL FORCES GROUP (SG)

****************************************************************

* ASSUME THE FORCE EFFECTIVENESS OF EACH FORCE IS 1. IN THE
* TABLE BELOW ENTER THE PERCENTAGE OF THE FORCE EFFECTIVENESS
* THAT IS CONTRIBUTED BY THE FORCE'S RELIANCE ON THE
* ATTRIBUTE IN ACCOMPLISHING ITS MISSION.

| * | LETH | DEPL | MOBL | SUST | POLI | SURV |
|---|---|---|---|---|---|---|
| *UNITS | | | | | | |
| HD | 0.21 | 0.04 | 0.25 | 0.04 | 0.05 | 0.25 |
| LD | 0.07 | 0.07 | 0.05 | 0.21 | 0.21 | 0.09 |
| AC | 0.09 | 0.17 | 0.17 | 0.12 | 0.07 | 0.04 |
| SG | 0.12 | 0.12 | 0.12 | 0.17 | 0.17 | 0.05 |
| MF | 0.17 | 0.09 | 0.21 | 0.09 | 0.09 | 0.21 |
| AG | 0.25 | 0.05 | 0.07 | 0.05 | 0.04 | 0.12 |
| AA | 0.05 | 0.21 | 0.09 | 0.07 | 0.12 | 0.17 |
| SF | 0.04 | 0.25 | 0.04 | 0.25 | 0.25 | 0.07 |

## APPENDIX C GAMS PROGRAM CODE

```
$TITLE CHARLES FLETCHER
$STITLE FORCE STRUCTURE DECISION AID
                  *----GAMS   OPTIONS   AND   DOLLAR   CONTROL
OPTIONS----*

$OFFUPPER OFFSYMXREF OFFSYMLIST

  OPTIONS LIMCOL=0,LIMROW=0,SOLPRINT=OFF;
  OPTIONS RESLIM=1000,ITERLIM=10000,OPTCR=0.001;

*-----------DEFINITIONS AND DATA-----------------*
  SETS
    U UNITS /HD,LD,AC,SG,MF,AA,AG,SF/
    I ATTRIBUTES /LETH,DEPL,MOBL,SUST,POLI,SURV/
    REP NUMBER OF REPS   /1*5/                    ;

  PARAMETERS

       FAR(I) FORCE ATTRIBUTE REQUEST
             / LETH      .19
               DEPL      .14
               MOBL      .26
               SUST      .13
               POLI      .17
               SURV      .11  /

       MINS(U) MINIMUM VALUE FOR EACH UNIT
             / HD  8
               LD  2
               AC  8
               SG  4
               MF  2
               AG  6
               AA  6
               SF  2  /

       MAXES(U) MAXIMUM VALUE FOR EACH UNIT
```

```
                / HD 16
                  LD  6
                  AC 14
                  SG  8
                  MF  4
                  AG 18
                  AA 18
                  SF 10   / ;

 SCALAR       SIZE       ;
 SIZE =        55.000000       ;

*------------UNIT ATTRIBUTE WEIGHT TABLE-----------*
     TABLE
     F(U,I)   FORCE MATRIX
           LETH     DEPL     MOBL     SUST     POLI     SURV
HD       .21000   .04000   .25000   .04000   .05000   .25000
LD       .07000   .07000   .05000   .21000   .21000   .09000
AC       .09000   .17000   .17000   .12000   .07000   .04000
SG       .12000   .12000   .12000   .17000   .17000   .05000
MF       .17000   .09000   .21000   .09000   .09000   .21000
AG       .25000   .05000   .07000   .05000   .04000   .12000
AA       .05000   .21000   .09000   .07000   .12000   .17000
SF       .04000   .25000   .04000   .25000   .25000   .07000     ;

*--------------------MODEL------------------------*

 VARIABLE
    MAXDEV              MINIMIZE MAX DEVIATION
    Z                   MAXIMUM DEVIATION
    R(I)                TOTAL ATTRIBUTES REQUESTED
    R1(I)               TOTAL ATTRIBUTES DELIVERED
    R2(I)               REQUESTED - DELIVERED
    R3(I)               SQUARED DIFFERENCES
    R4                  TOTAL SQUARED DIFFERENCES
    POWER               SUM OF DELIVERED ATTRIBUTES;
 INTEGER VARIABLE
    X(U)                OPTIMUM NUMBER OF UNITS     ;
 EQUATIONS
     UPPER(I)           UPPER LIMIT OF DEVIATION
     LOWER(I)           LOWER LIMIT OF DEVIATION
     OBJ                MINIMIZE THE MAXIMUM DEVIATION
```

```
      MINIMUM(U)         OBSERVE MIN NUMBER OF UNITS
      MAXIMUM(U)         OBSERVE MAX NUMBER OF UNITS
      STRENGTH           ESITMATE FORCE SIZE
      ROLLUP(I)          FIND REQUESTED DIRRERENCES
      ROLLUP1(I)         FIND DELIVERED DIFFERENCES   ;

*-------------MINIMIZE----------------------------*

    OBJ..   MAXDEV =E= Z                               ;

*------------SUBJECT TO---------------------------*

    UPPER(I)..     SUM(U,X(U)*(F(U,I)-FAR(I))) =L=  Z;
    LOWER(I)..     SUM(U,X(U)*(F(U,I)-FAR(I))) =G= -Z;
    STRENGTH..     SIZE         =L=   SUM(U,X(U))      ;
    MINIMUM(U)..   X(U)         =G=   MINS(U)          ;
    MAXIMUM(U)..   X(U)         =L=   MAXES(U)         ;
    ROLLUP(I)..    SUM(U,FAR(I)*X(U)) =E= R(I)         ;
    ROLLUP1(I)..   SUM(U,X(U)*F(U,I)) =E= R1(I)        ;

    MODEL FAR10  /ALL/
*-------------------LOOP----------------------
    SOLVE FAR10 USING RMIP MINIMIZING MAXDEV      ;
    OPTION X:4:0:1     ;
    DISPLAY X.L        ;
    OPTION FAR:4:0:1   ;
    DISPLAY FAR        ;
    OPTION R:4:0:1     ;
    OPTION R1:4:0:1    ;
    OPTION R2:4:0:1    ;
    DISPLAY R.L        ;

    DISPLAY R1.L       ;
    POWER.L = SUM(I,R1.L(I))     ;
    OPTION POWER:4:0:1;
    DISPLAY POWER.L   ;
    R2.L(I) = R.L(I)-R1.L(I)     ;
    DISPLAY R2.L       ;
    R3.L(I) = SQR(R2.L(I))       ;
    OPTION R3:4:0:1    ;
    DISPLAY R3.L       ;
    R4.L = SUM(I,R3.L(I))        ;
```

```
OPTION R4:4:0:1    ;
DISPLAY R4.L       ;
```

# APPENDIX D GAMS LISTING

```
GAMS 2.05 PC AT/XT                91/08/22 13:11:16  PAGE      1
CHARLES FLETCHER
FORCE STRUCTURE DECISION AID


*----GAMS OPTIONS AND DOLLAR CONTROL OPTIONS----*


  OPTIONS LIMCOL=0,LIMROW=0,SOLPRINT=OFF;
  OPTIONS RESLIM=1000,ITERLIM=10000,OPTCR=0.001;

*-----------DEFINITIONS AND DATA-----------------*
  SETS
    U UNITS /HD,LD,AC,SG,MF,AA,AG,SF/
    I ATTRIBUTES /LETH,DEPL,MOBL,SUST,POLI,SURV/
    REP NUMBER OF REPS    /1*5/                         ;

  PARAMETERS

       FAR(I) FORCE ATTRIBUTE REQUEST
             / LETH      .15
               DEPL      .16
               MOBL      .24
               SUST      .11
               POLI      .24
               SURV      .09  /
```

```
        MINS(U) MINIMUM VALUE FOR EACH UNIT
                / HD  8
                  LD  2
                  AC  8
                  SG  4
                  MF  2
                  AG  6
                  AA  6
                  SF  2  /

        MAXES(U) MAXIMUM VALUE FOR EACH UNIT
                / HD 16
                  LD  6
                  AC 14
                  SG  8
                  MF  4
                  AG 18
                  AA 18
                  SF 10  / ;

SCALAR      SIZE      ;
SIZE =        55.000000      ;
```

```

*------------UNIT ATTRIBUTE WEIGHT TABLE-----------*
        TABLE
        F(U,I)  FORCE MATRIX
              LETH     DEPL     MOBL     SUST     POLI     SURV
HD          .21000   .04000   .25000   .04000   .05000   .25000
LD          .07000   .07000   .05000   .21000   .21000   .09000
AC          .09000   .17000   .17000   .12000   .07000   .04000
SG          .12000   .12000   .12000   .17000   .17000   .05000
MF          .17000   .09000   .21000   .09000   .09000   .21000
AG          .25000   .05000   .07000   .05000   .04000   .12000
AA          .05000   .21000   .09000   .07000   .12000   .17000
SF          .04000   .25000   .04000   .25000   .25000   .07000
;

*-------------------MODEL------------------------*

 VARIABLE
    MAXDEV                 MINIMIZE MAX DEVIATION
    Z                      MAXIMUN DEVIATION
    R(I)                   TOTAL ATTRIBUTES REQUESTED
    R1(I)                  TOTAL ATTRIBUTES DELIVERED
    R2(I)                  REQUESTED - DELIVERED
    R3(I)                  SQUARED DIFFERENCES
    R4                     TOTAL SQUARED DIFFERENCES
    POWER                  SUM OF DELIVERED ATTRIBUTES;
 INTEGER VARIABLE
    X(U)                   OPTIMUM NUMBER OF UNITS    ;
 EQUATIONS
     UPPER(I)              UPPER LIMIT OF DEVIATION
     LOWER(I)              LOWER LIMIT OF DEVIATION
     OBJ                   MINIMIZE THE MAXIMUM DEVIATION
     MINIMUM(U)            OBSERVE MIN NUMBER OF UNITS
     MAXIMUM(U)            OBSERVE MAX NUMBER OF UNITS
     STRENGTH              ESITMATE FORCE SIZE
     ROLLUP(I)             FIND REQUESTED DIRRERENCES
     ROLLUP1(I)            FIND DELIVERED DIFFERENCES  ;

```

```
*------------MINIMIZE----------------------------*

   OBJ..    MAXDEV =E= Z                              ;

*-----------SUBJECT TO---------------------------*

   UPPER(I)..     SUM(U,X(U)*(F(U,I)-FAR(I))) =L=  Z;
   LOWER(I)..     SUM(U,X(U)*(F(U,I)-FAR(I))) =G= -Z;
   STRENGTH..     SIZE          =L=    SUM(U,X(U))      ;
   MINIMUM(U)..   X(U)          =G=    MINS(U)          ;
   MAXIMUM(U)..   X(U)          =L=    MAXES(U)         ;
   ROLLUP(I)..    SUM(U,FAR(I)*X(U)) =E= R(I)           ;
   ROLLUP1(I)..   SUM(U,X(U)*F(U,I)) =E= R1(I)          ;

   MODEL FAR10  /ALL/
*--------------------LOOP----------------------
   SOLVE FAR10 USING RMIP MINIMIZING MAXDEV      ;
   OPTION X:4:0:1     ;
   DISPLAY X.L        ;
   OPTION FAR:4:0:1   ;
   DISPLAY FAR        ;
   OPTION R:4:0:1     ;
   OPTION R1:4:0:1    ;
   OPTION R2:4:0:1    ;
   DISPLAY R.L        ;
   DISPLAY R1.L       ;
   POWER.L = SUM(I,R1.L(I))     ;
   OPTION POWER:4:0:1;
   DISPLAY POWER.L    ;
   R2.L(I) = R.L(I)-R1.L(I)     ;
   DISPLAY R2.L       ;
   R3.L(I) = SQR(R2.L(I))       ;
   OPTION R3:4:0:1    ;
   DISPLAY R3.L       ;
   R4.L = SUM(I,R3.L(I))        ;
   OPTION R4:4:0:1    ;
   DISPLAY R4.L       ;
```

COMPILATION TIME     =        0.035 MINUTES

```
SOLUTION REPORT     SOLVE FAR10 USING RMIP FROM LINE 102


              S O L V E     S U M M A R Y

     MODEL   FAR10                 OBJECTIVE  MAXDEV
     TYPE    RMIP                  DIRECTION  MINIMIZE
     SOLVER  ZOOM                  FROM LINE  102

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE                6.1967

 RESOURCE USAGE, LIMIT          0.208      1000.000
 ITERATION COUNT, LIMIT        40         10000

 Z O O M / X M P    ---    VERSION 2.1 APR 1989

 Courtesy of Dr Roy E. Marsten,
             Department of Management Information Systems,
             University of Arizona,
             Tucson     Arizona  85721,  U.S.A.


 No options file found - using defaults.

 Work space needed (estimate)    --     7053 words.
 Work space available            --    33682 words.


**** REPORT SUMMARY :          0     NONOPT
                               0 INFEASIBLE
                               0  UNBOUNDED
```

```
E X E C U T I N G
----    104 VARIABLE  X.L              OPTIMUM NUMBER OF UNITS

HD  9.1667
LD  3.8333
AC  8.0000
SG  8.0000
MF  4.0000
AA  6.0000
AG  6.0000
SF 10.0000


----    106 PARAMETER FAR              FORCE ATTRIBUTE REQUEST

LETH 0.1500
DEPL 0.1600
MOBL 0.2400
SUST 0.1100
POLI 0.2400
SURV 0.0900


----    110 VARIABLE  R.L             TOTAL ATTRIBUTES REQUESTED

LETH  8.2500
DEPL  8.8000
MOBL 13.2000
SUST  6.0500
POLI 13.2000
SURV  4.9500
```

```
----     111 VARIABLE  R1.L          TOTAL ATTRIBUTES DELIVERED

LETH 6.7533
DEPL 7.3750
MOBL 7.0033
SUST 7.0717
POLI 7.0033
SURV 6.6367


----     114 VARIABLE  POWER.L          =        41.8433 SUM OF
DELIVERED ATTRIBUTES

E X E C U T I N G


----     116 VARIABLE  R2.L          REQUESTED - DELIVERED

LETH  1.4967
DEPL  1.4250
MOBL  6.1967
SUST -1.0217
POLI  6.1967
SURV -1.6867


----     119 VARIABLE  R3.L          SQUARED DIFFERENCES

LETH  2.2400
DEPL  2.0306
MOBL 38.3987
SUST  1.0438
POLI 38.3987
SURV  2.8448


---- 122 VARIABLE  R4.L  =  84.9566 TOTAL SQUARED DIFFERENCES
```

```
**** FILE SUMMARY

INPUT   F:\BIN\BASE.GMS
OUTPUT  F:\BIN\BASE.LST

EXECUTION TIME       =        0.041 MINUTES
```

## APPENDIX E READIT PROGRAM CODE

```
** READIT PROGRAM, THIS PROGRAM PROMPTS THE USER FOR A LISTING
** FILE NAME FROM GAMS OUTPUT. THIS PROGRAM READS THE FILE AND
** CREATES A FILE WITH THE SAME NAME AS THE LISTING EXCEPT
** WITH A FILE EXTENSION OF ' '.OUT. THE OUTPUT FILE CONTAINS
** THE VECTOR X(U) ONLY.
        PROGRAM READIT
        INTEGER I
        CHARACTER FNAME*10,TEST*4,ANSWER*12
      & ,TRY*4,ANSWER1*24,FNAME1*14
        WRITE (*,100)
100     FORMAT (' ENTER LISTING FILENAME WITH NO SUFFIX')
        READ(*, ' (A) ')FNAME
        OPEN(30,FILE =FNAME//'.LST')
        WRITE(*,*)FNAME
        FNAME1=FNAME//'.OUT'
        WRITE(*,*)FNAME1
        OPEN(40,FILE = FNAME1)
        DATA TEST /'----'/
101     READ (30,102,END = 106)TRY
102     FORMAT(A4)
        IF(TEST.EQ.TRY)GOTO 103
        GOTO 101
103     CONTINUE
        DO 1,I=1,10
           IF(I.LT.10)THEN
             READ (30,104)ANSWER
             WRITE(40,*)ANSWER
           ELSE
             READ (30,105)ANSWER1
             WRITE(40,*)ANSWER1
           ENDIF
  1     CONTINUE
104     FORMAT(A12)
105     FORMAT(//,T44,A24)
106     STOP
        END
```

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